

PSAT Training

Part 01

PSAT Overview



U.S. Department
of Energy

UChicago ►
Argonne_{LLC}



A U.S. Department of Energy laboratory
managed by UChicago Argonne, LLC

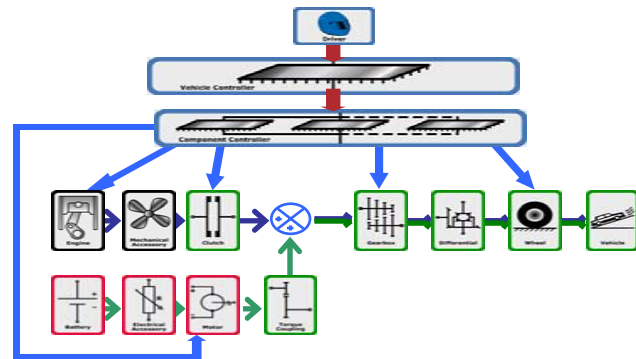
Aymeric Rousseau
Argonne National Laboratory



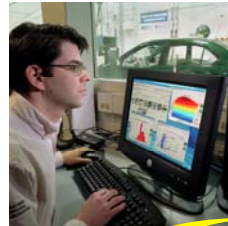
Outline

- ANL Philosophy
- PSAT Overview
- Example of Studies
- Perspectives

ANL Capabilities Designed for Vehicle Systems Analysis



Modeling and Simulation (PSAT)



Simulation

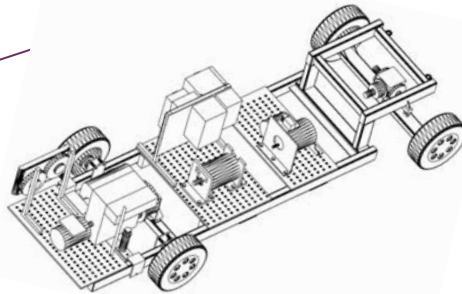


Validation

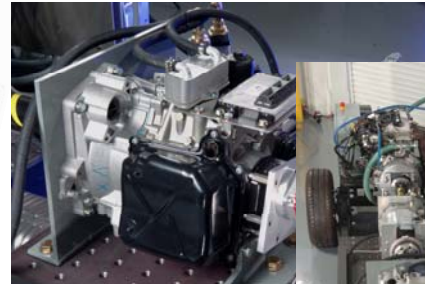


Benchmarking & Validation

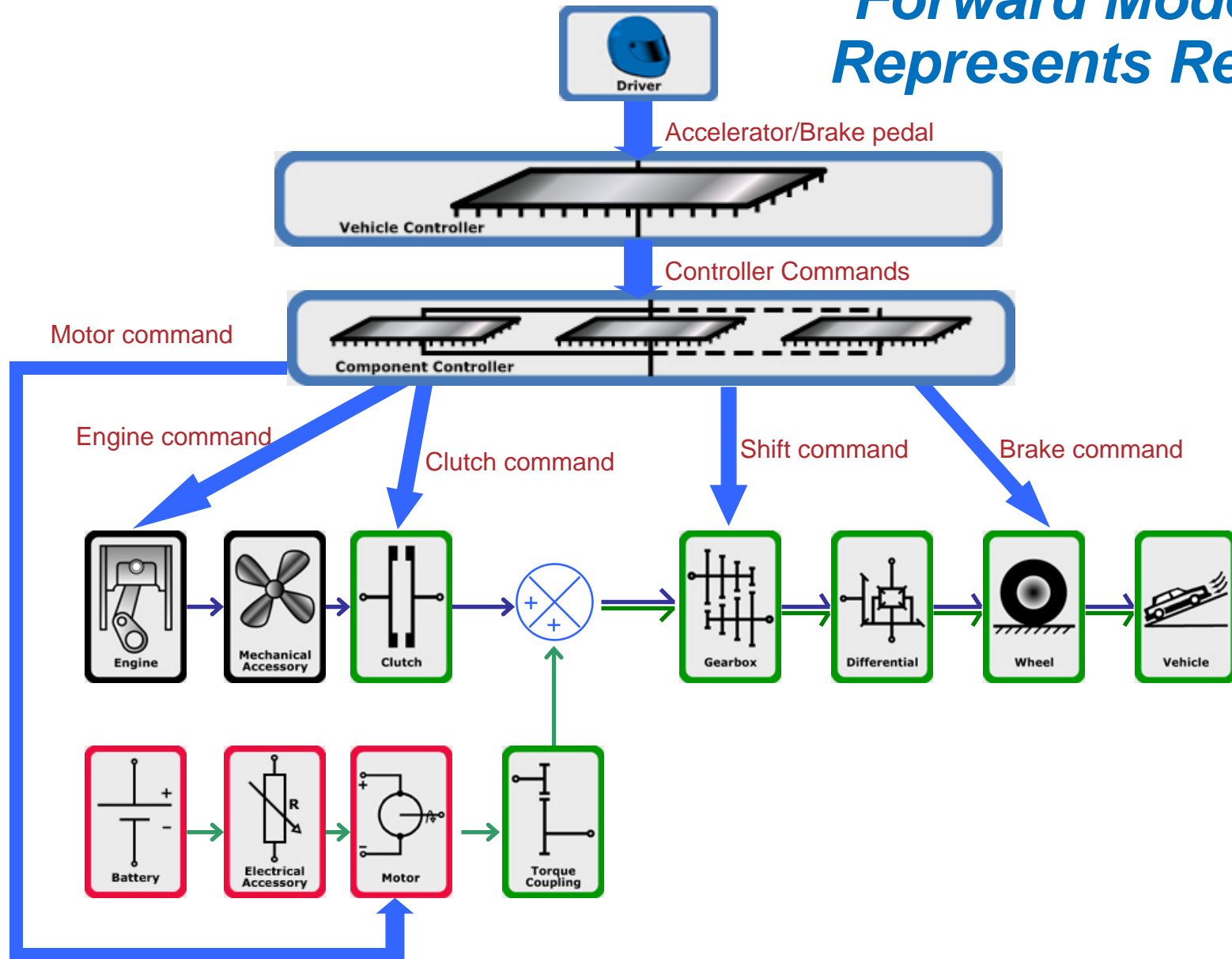
Emulation



Component/System Emulation Using Hardware-In-the-Loop (HIL)

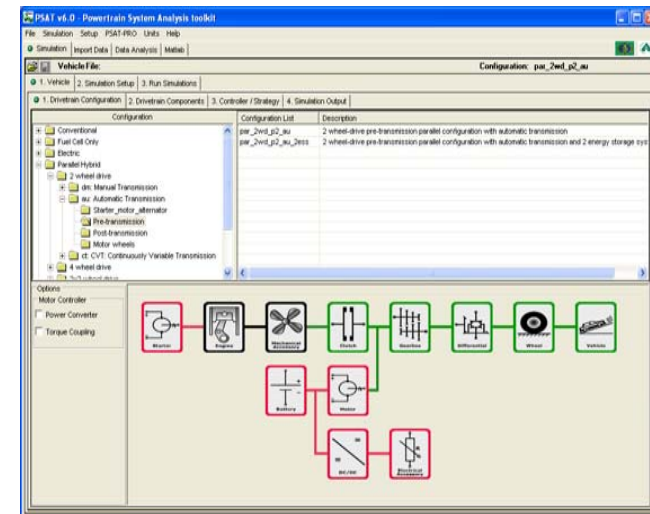


Forward Modeling Represents Reality



Developed to meet the requirements of automotive engineering throughout the development process

- Forward-looking model
- Wide range of vehicle applications from light to heavy duty
- Unrivalled number of predefined configurations
- Easy implementation of proprietary data, component models, control strategies or drive cycles
- Easy to use Graphical User Interface
- Possibility to use the control strategies for Hardware-in-the-Loop / Software-in-the-Loop
- Designed for co-simulation environment



What is PSAT Used for?

- Fuel economy
- Performance
- Component technology comparison
- Transmission ratios
- Component sizing
- Control strategy development
- Drivetrain configuration comparison
- Drive cycle impact
- HIL / RCP
- Model validation
- Test data analysis

Outline

- ANL Philosophy
- PSAT Overview
- Example of Studies
- Perspectives

PSAT Simulations Support R&D and Management Decisions

- After a thorough assessment, PSAT has been selected in 2004 as the primary vehicle model for all FreedomCAR and 21 CTP activities by the U.S.DOE, stating that *“All future code development and enhancements for OFCVT shall focus on PSAT and PSAT-PRO”*

- PSAT has been awarded a R&D100 Award in 2004 represented to the 100 most technologically significant new products and processes introduced into the market each year.

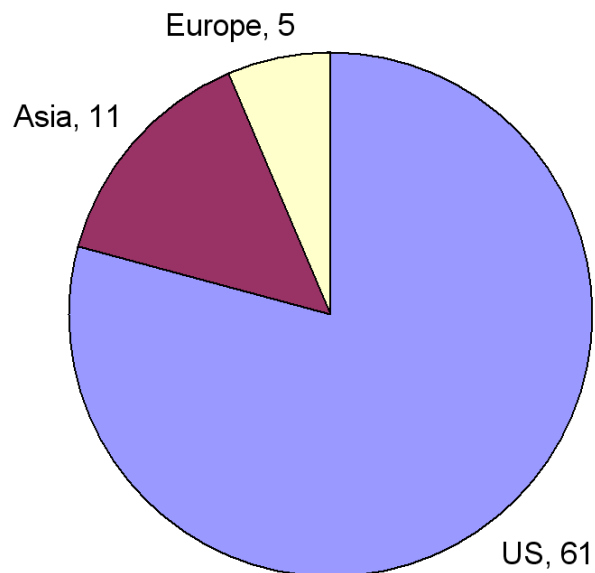


- PSAT has been awarded a Technology Transfer Award in 2007
- *“... We need a model that’s intuitive, easy to use, and provides accurate results. PSAT gives us that.”* Randy Yost - GM Engineering Specialist

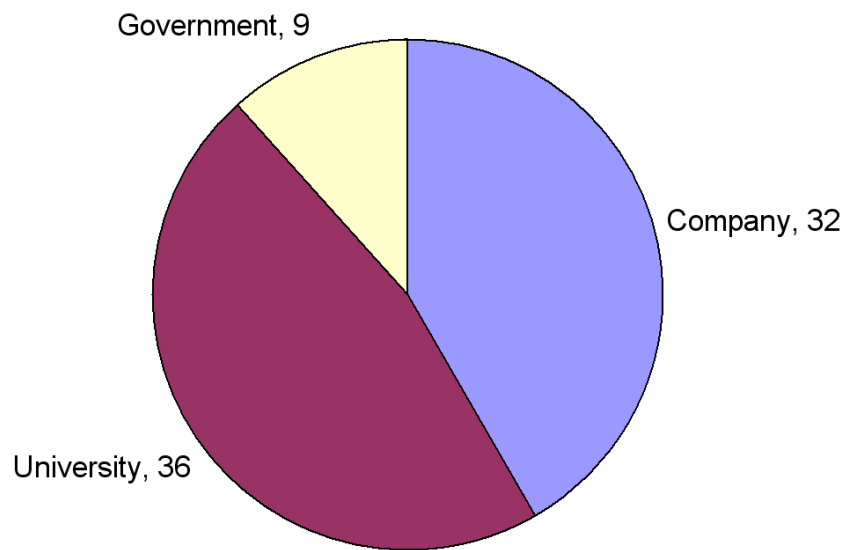
Large User Database Proof of Success



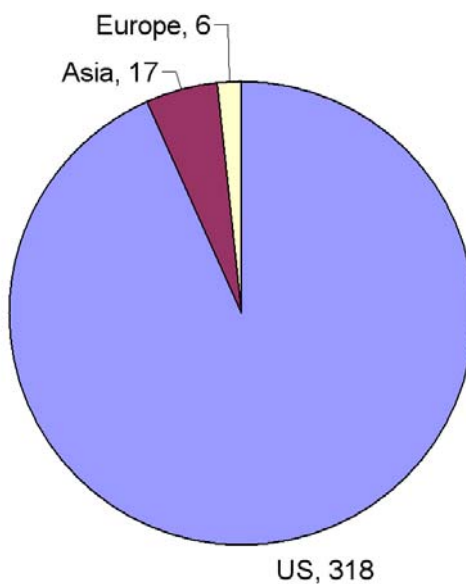
Numerous US Companies are Using PSAT



Licenses
Location Favors
US



Licenses
Distribution
Evenly Split



PSAT Close to
300 Users

As of August 2007

Different Users Have Different Needs

U.S.DOE

- Validated complete vehicle models
- Focused on fuel economy and performance
- Evaluate component in vehicle system context
- Evaluate fuel economy potential of future technologies (e.g. goals)

Car Companies

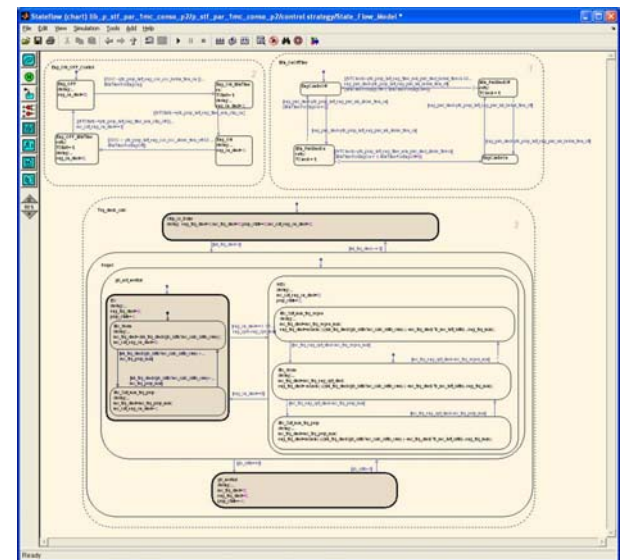
- Implement their own models/data/controls
- Also interested in drive quality & emissions
- Need to have different levels of modeling
- Interested in software architecture & post-processing tools

Suppliers

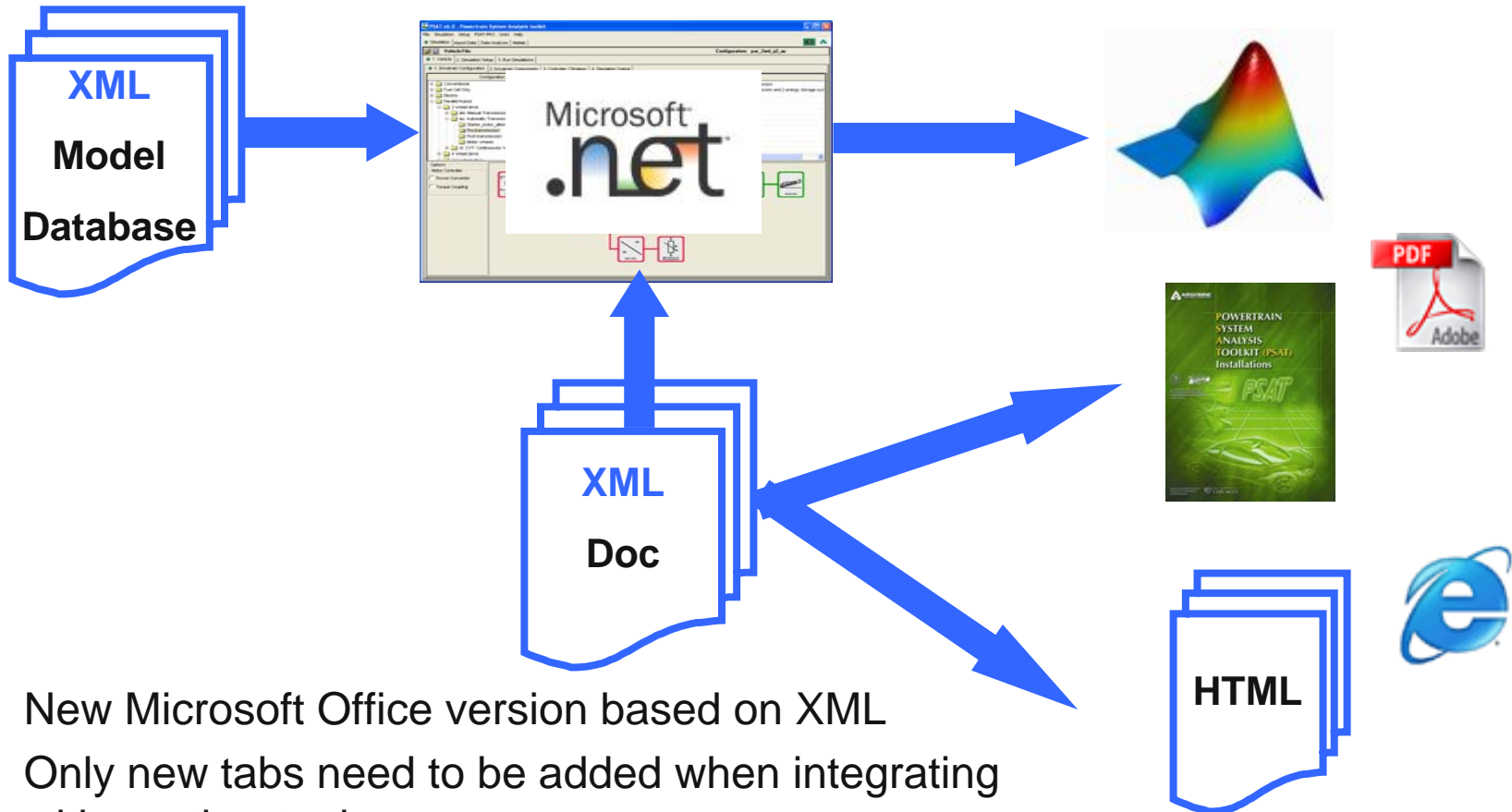
- Implement their component model / subsystems (reuse rest of PSAT models)
- Interested in software architecture & post-processing tools

PSAT V6.2 Released in December 2007

- Main new features and improvements include:
 - Enhanced GUI features including
 - *Ability to build trips*
 - *New test procedures (including EPA 2011 and PHEV)*
 - *Redesigned energy balance*
 - *Ability to select transients*
 - Additional powertrain configurations (including GM 2 mode and Lexus RX400h)
 - Vehicle level control strategies redesigned in StateFlow



PSAT Architecture Suited for Integration with other Software



- New Microsoft Office version based on XML
- Only new tabs need to be added when integrating with another tool

GUI Provides Easy Access to Features

PSAT 6.2 - Powertrain System Analysis Toolkit

File Simulation Setup PSAT-PRO Units Matlab Help

Simulation Import Data Data Analysis ?

Vehicle File: Configuration: conv_2wd_dm

1. Vehicle 2. Simulation Setup 3. Reporting 4. Run Simulations

1. Drivetrain Configuration 2. Drivetrain Components 3. Controller / Strategy 4. Transients 5. Simulation Output

Configuration

- Conventional
 - 2 wheel drive
 - dm: Manual Transmission
 - au: Automatic Transmission
 - ct: CVT: Continuously Variab
 - 4 wheel drive
- Fuel Cell Only
- Electric
- Parallel Hybrid
- Series Electric Hybrid

Configuration List

Configuration List	Description
conv_2wd_dm	2 wheel-drive conventional configuration with manual transmission

Options

Generator

☐ Power Converter

Diagram:

Starter Engine Mechanical Accessory Clutch Gearbox Differential Wheel Vehicle

Battery Generator Torque Coupling Electrical Accessory

A Single Tool Throughout the Development Process

Build and compare large number of powertrain configurations

Easy selection of data, models, control strategies or drive cycles

Run batch mode

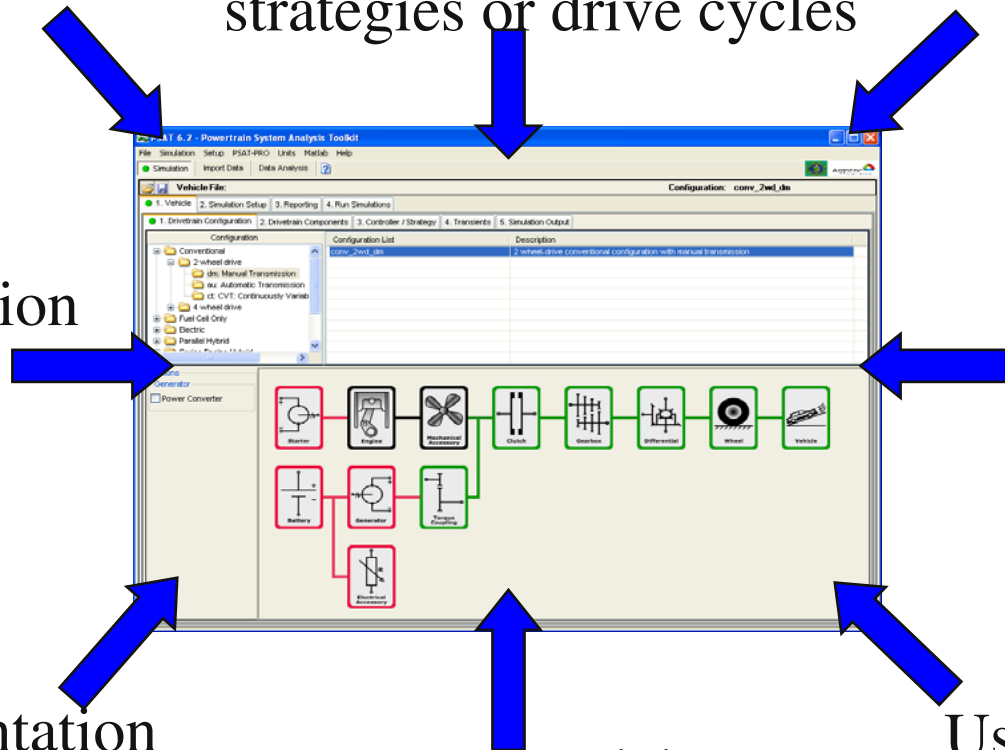
Ensure simulation traceability

Analyze and compare test and simulation data

Easy implementation of data, models, control strategies

Ensure model compatibilities

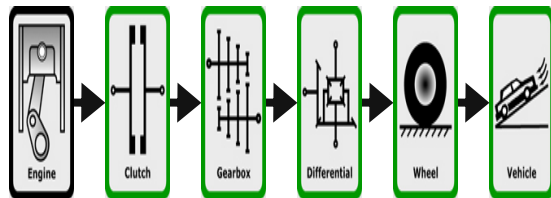
Use models and controls for HIL/RCP



Large Number of Configurations Achieved Through Automatic Building

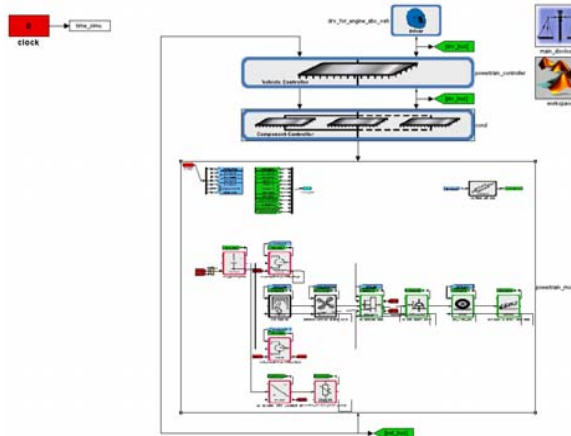
Option #1

Drag & Drop



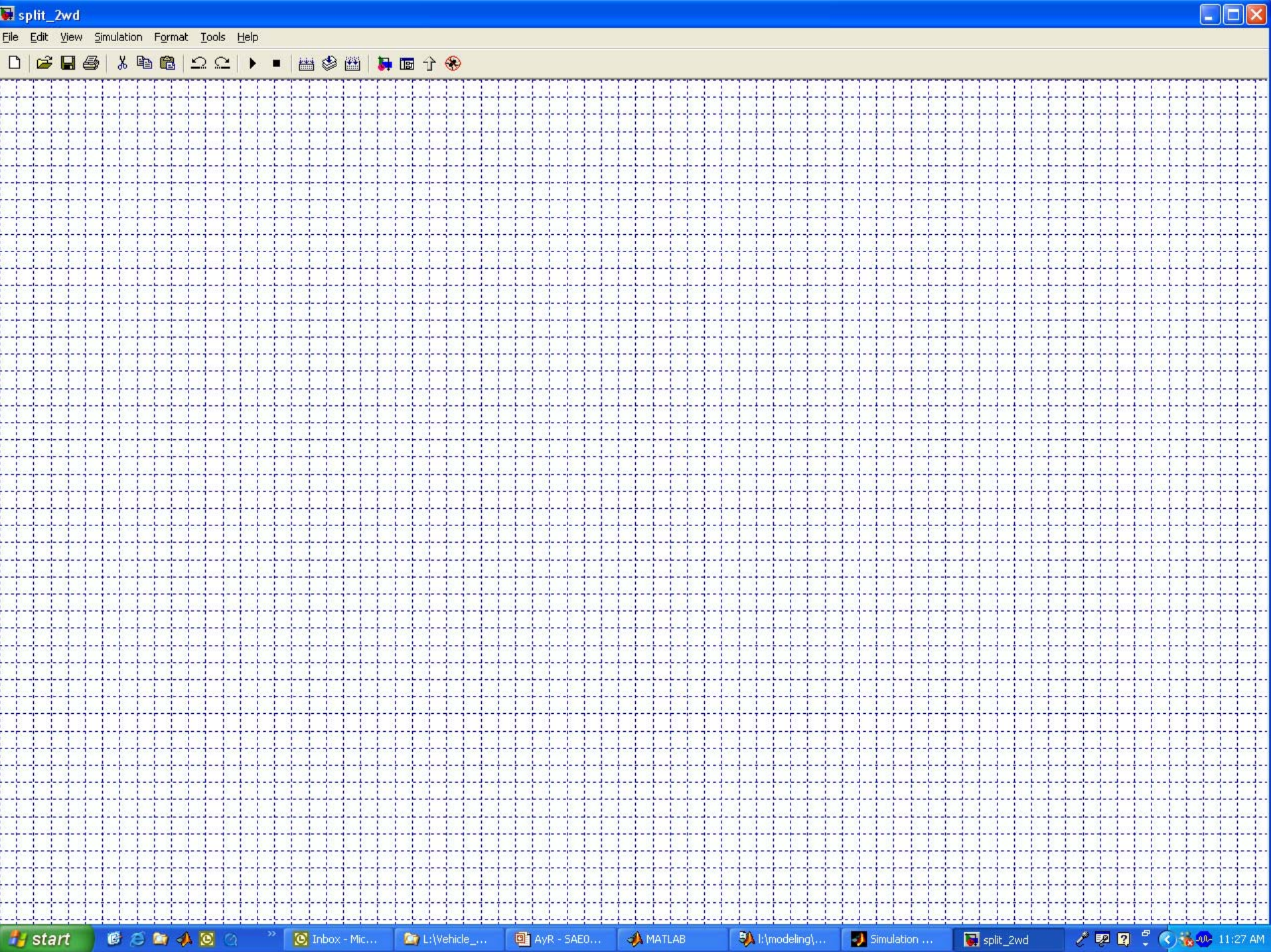
Option #2

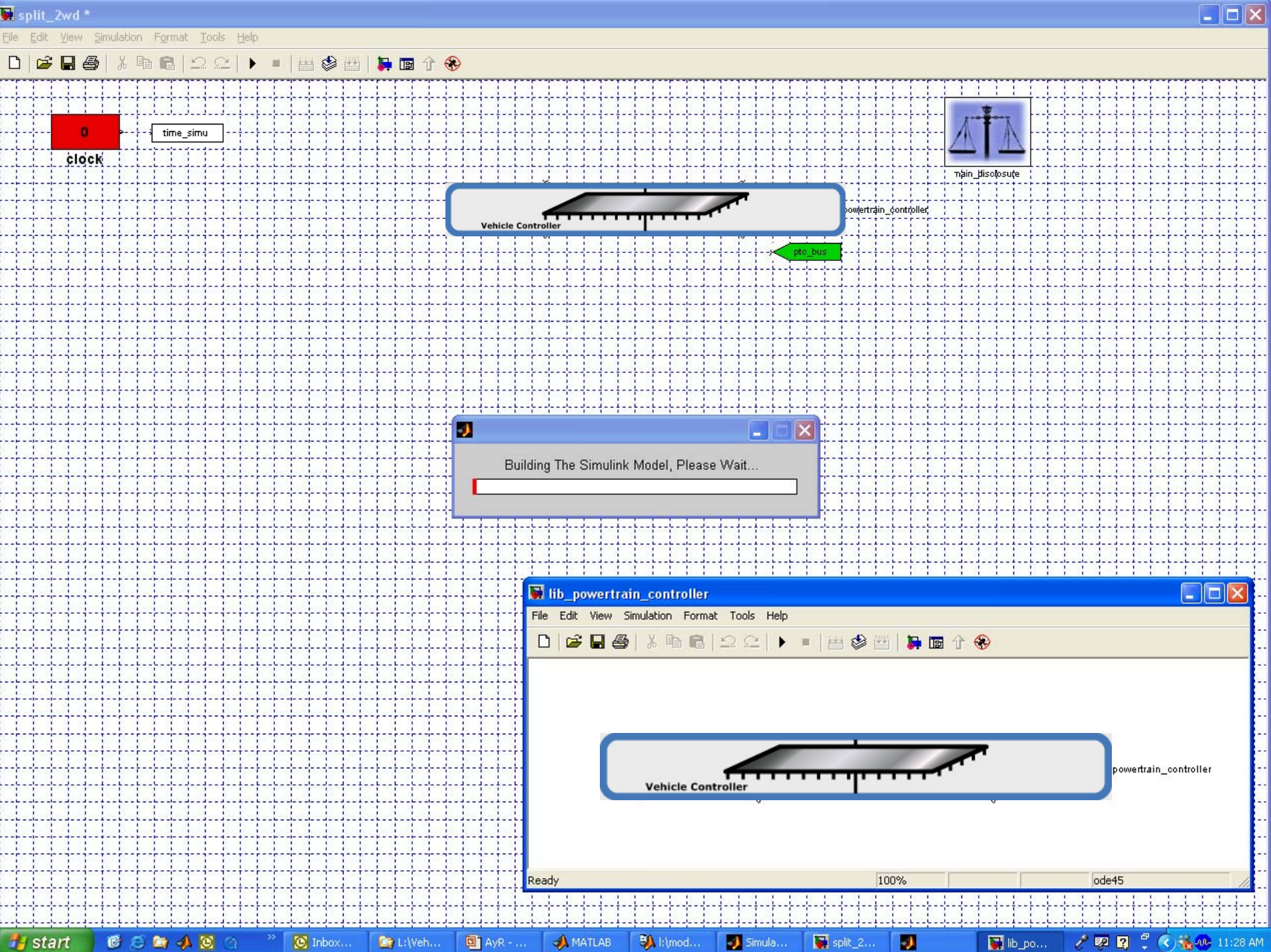
Save Entire Vehicles

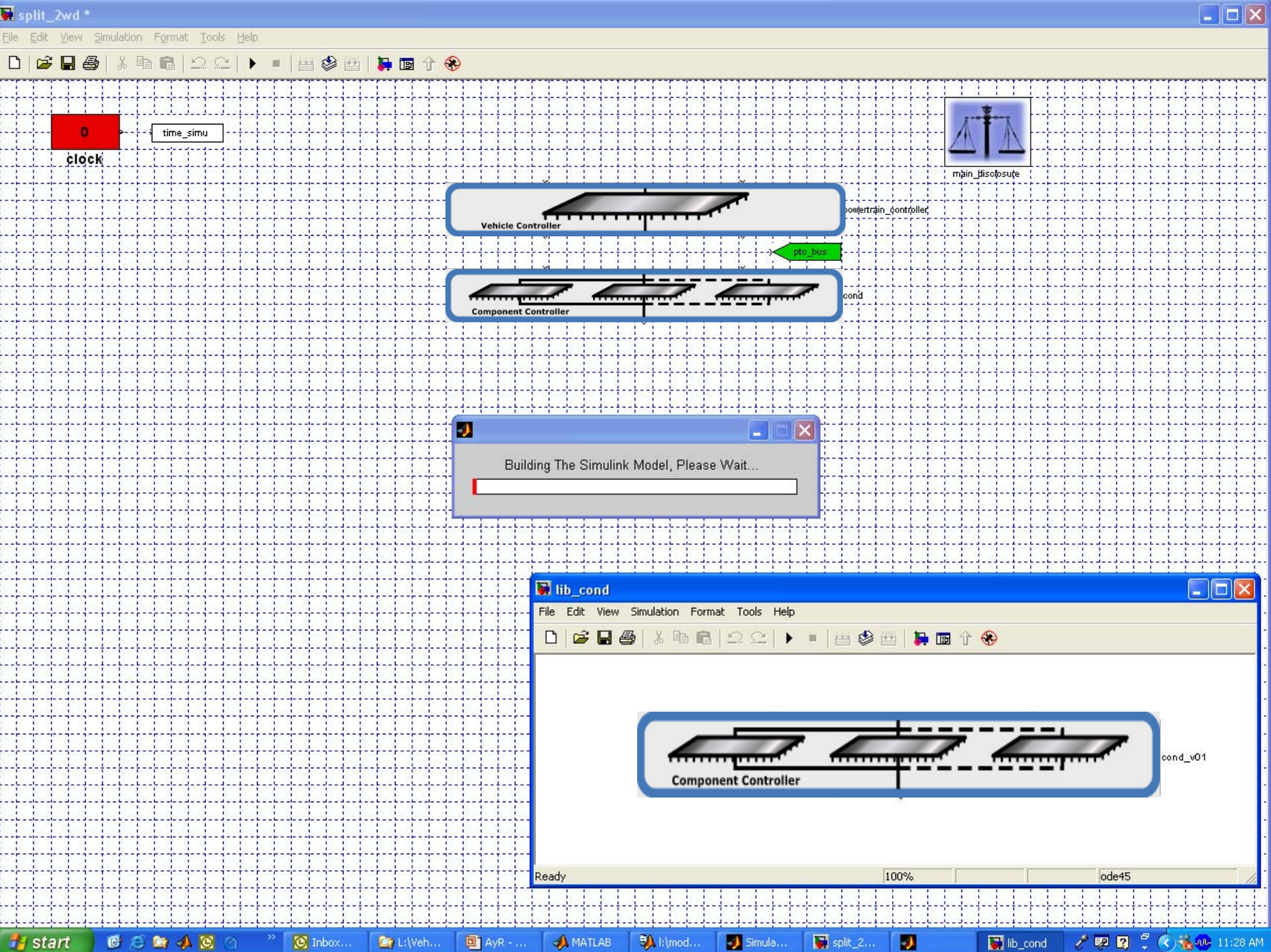


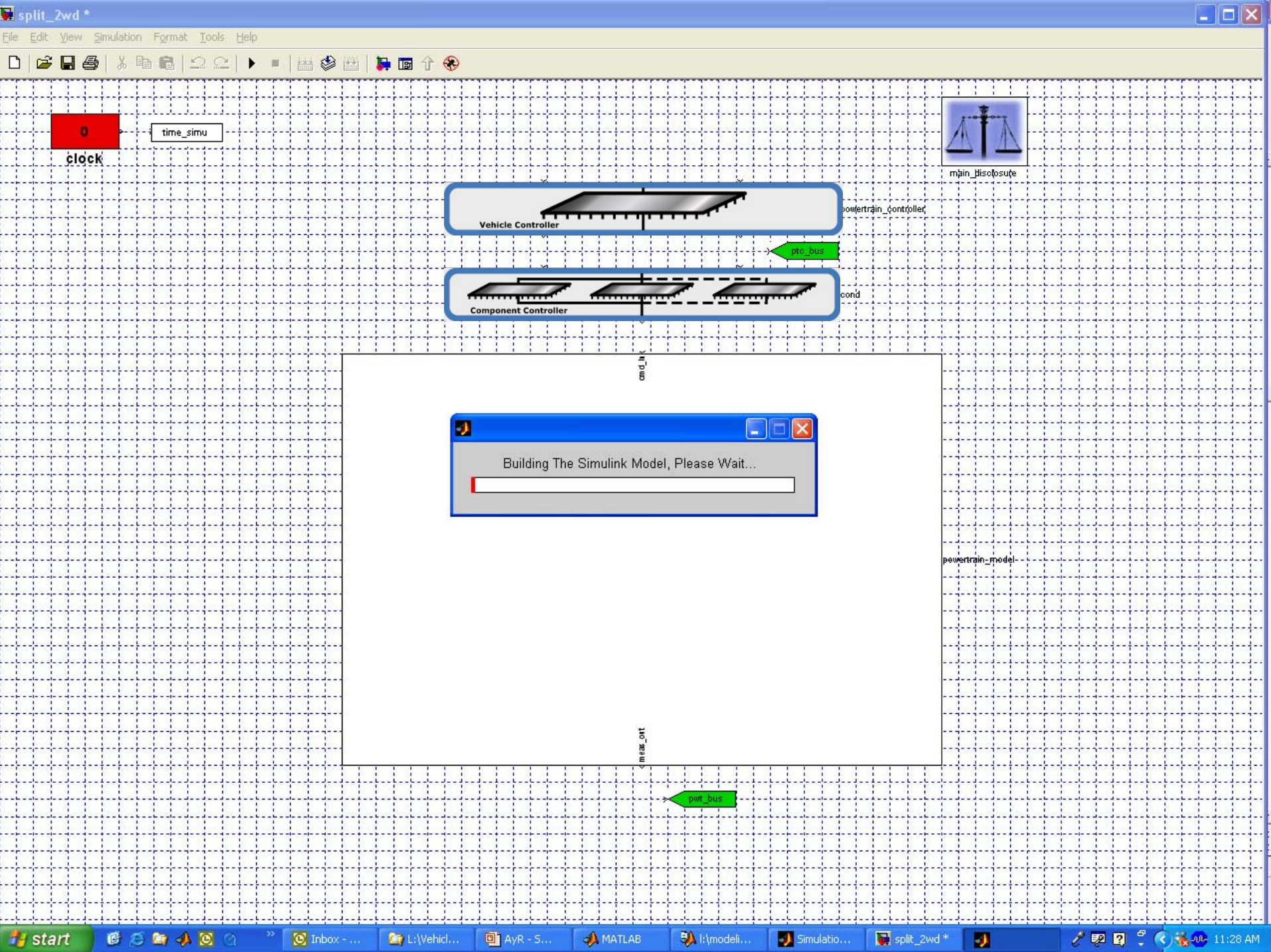
Solution

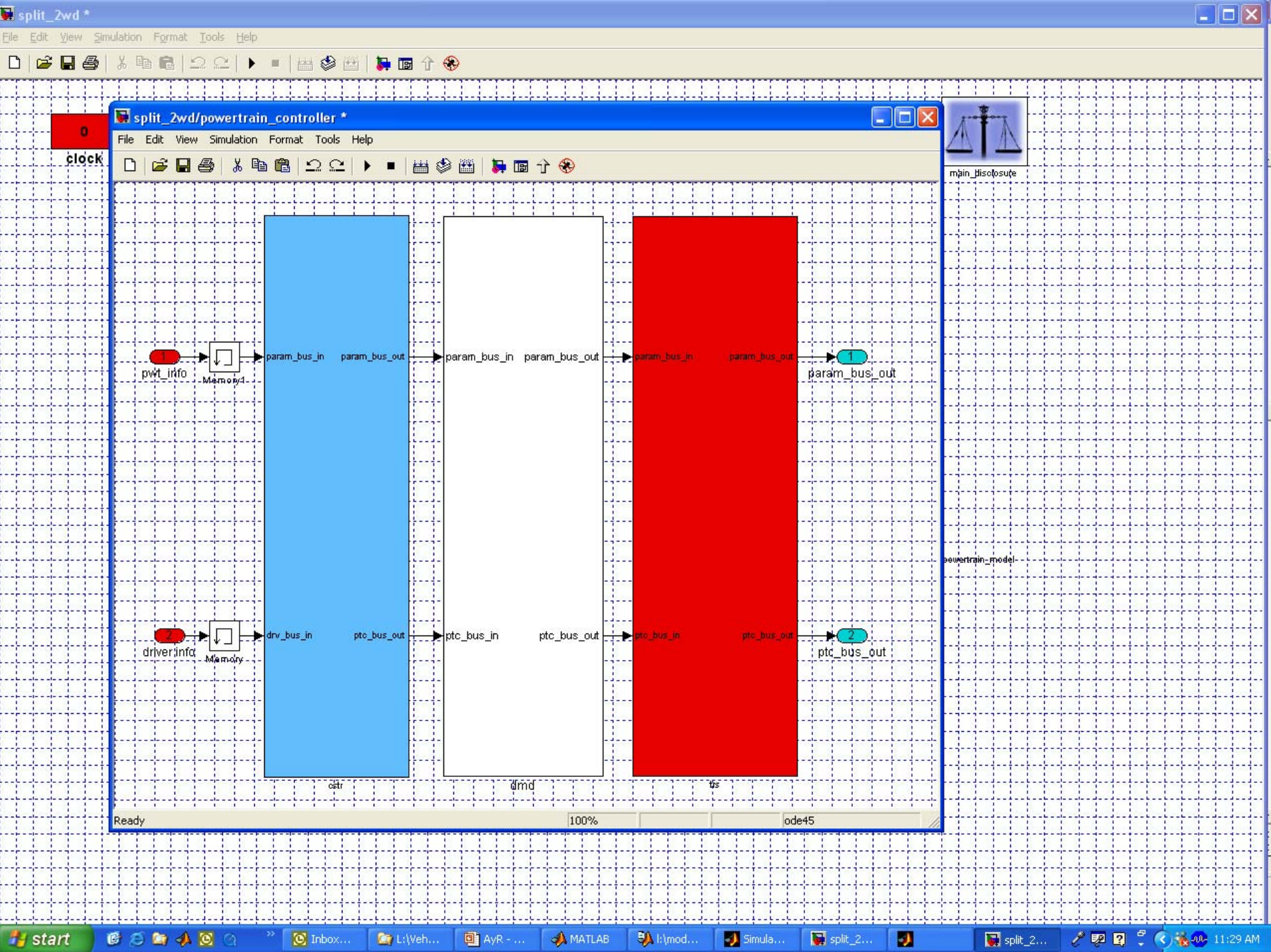
**Build
model
based on
users
choices
using
add_block
&
add_line**

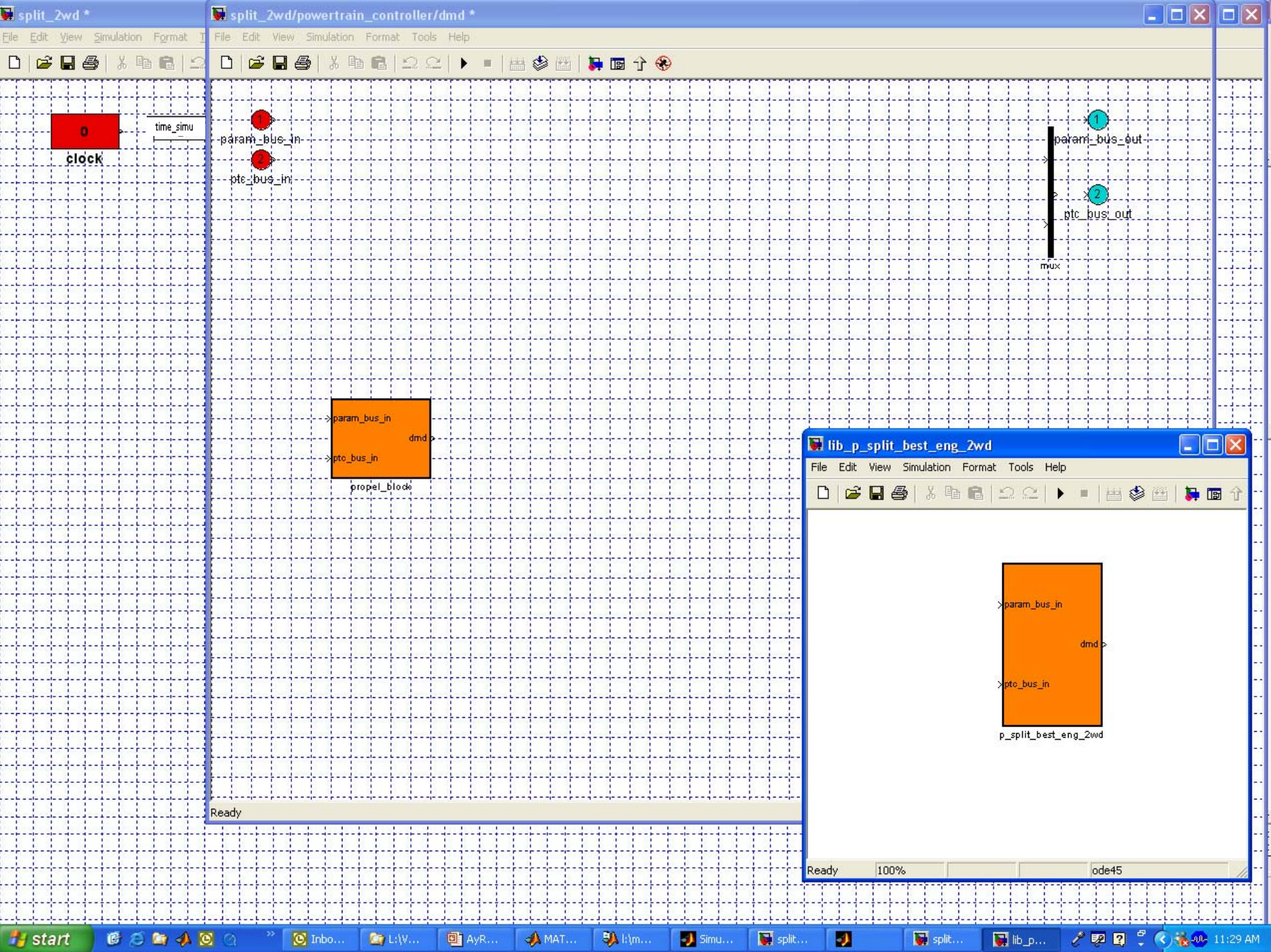


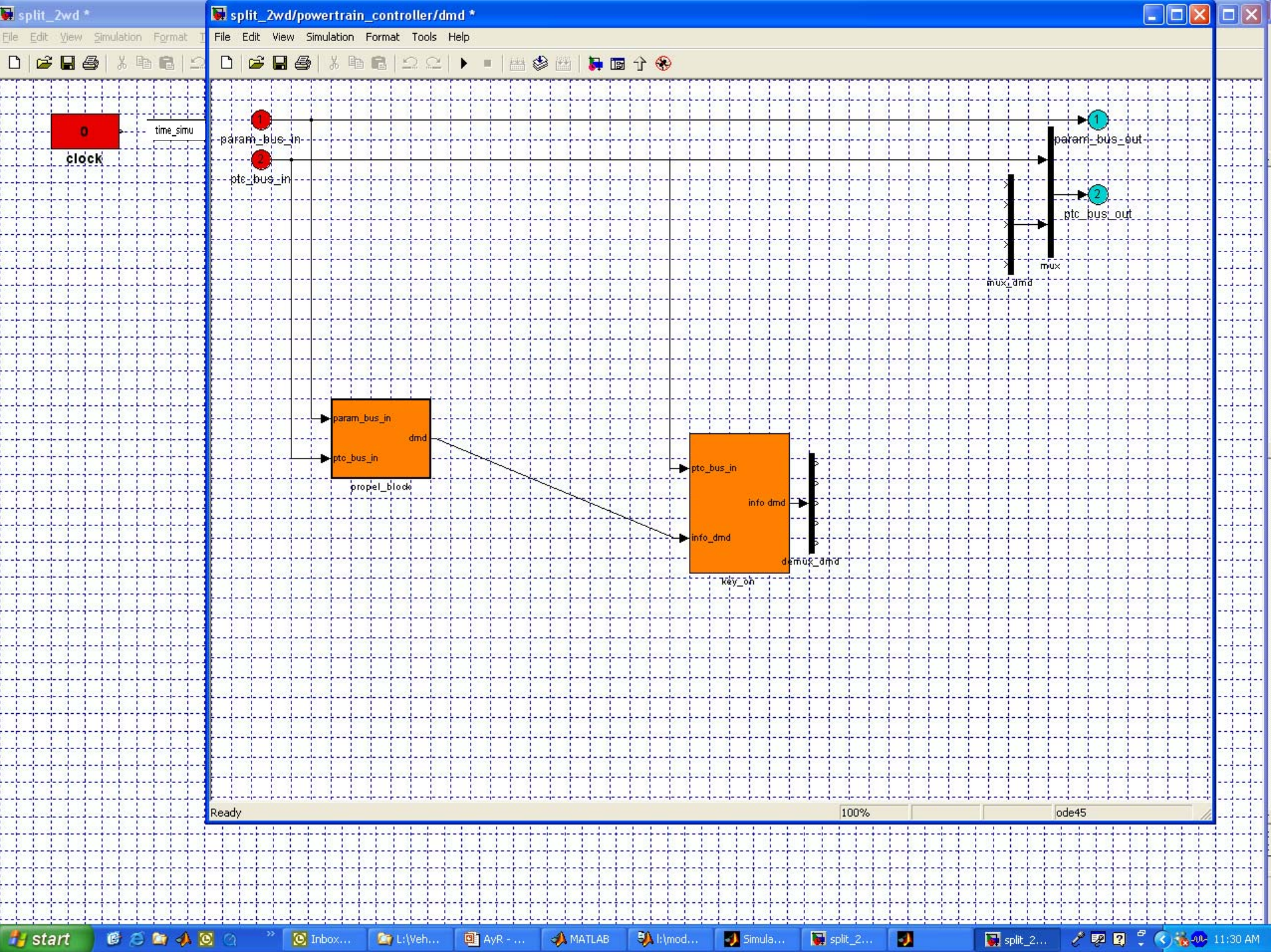


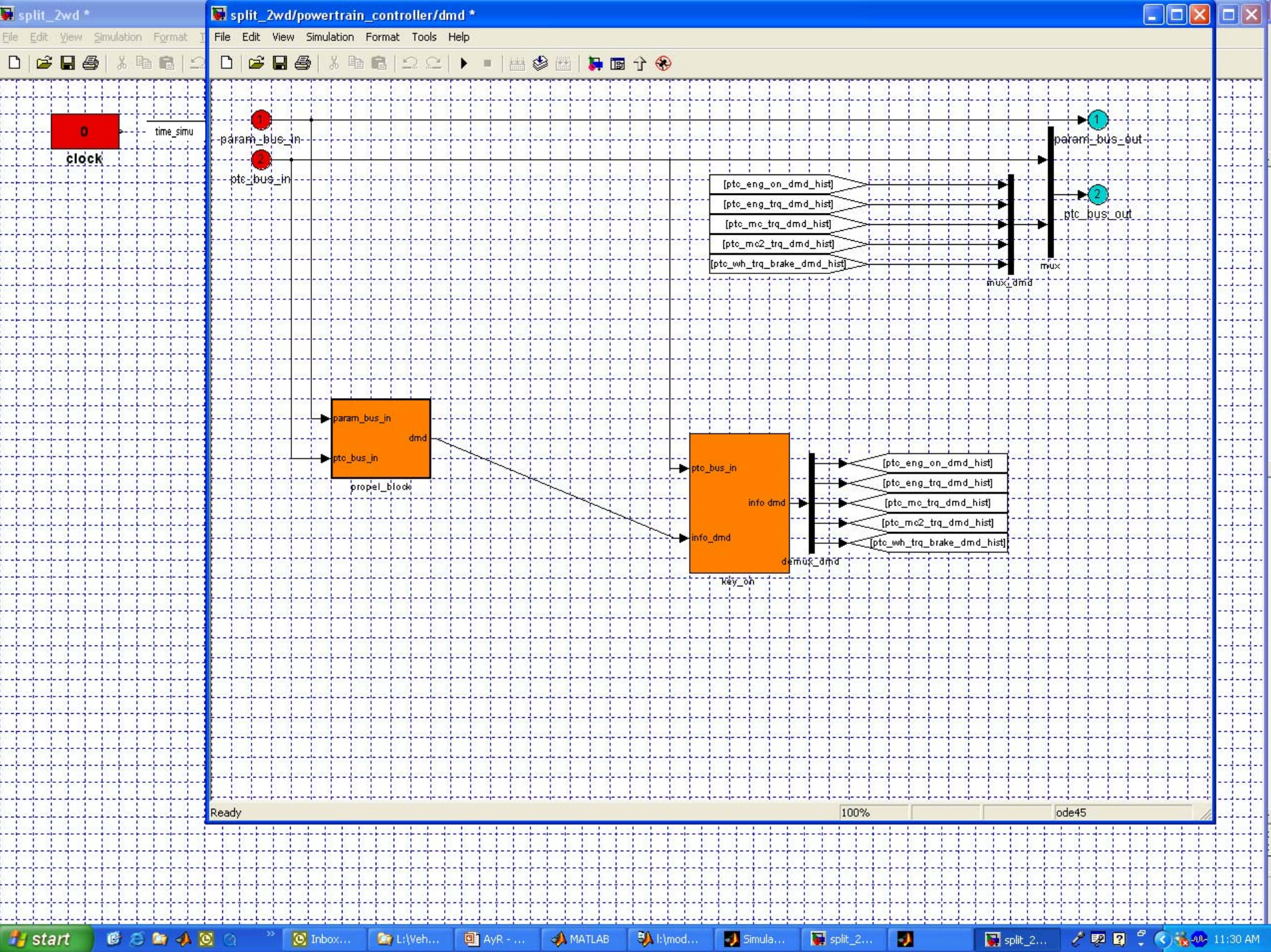


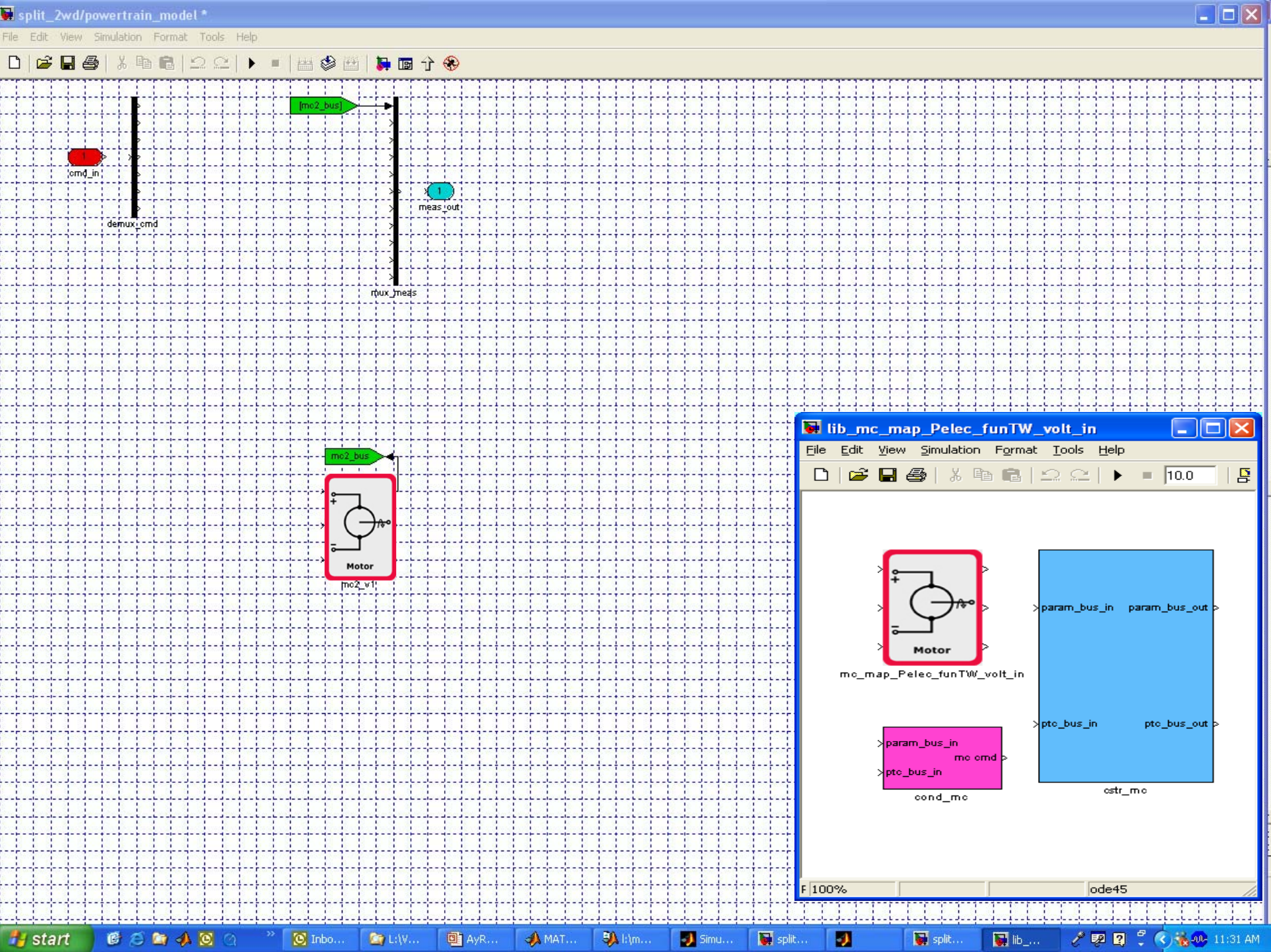


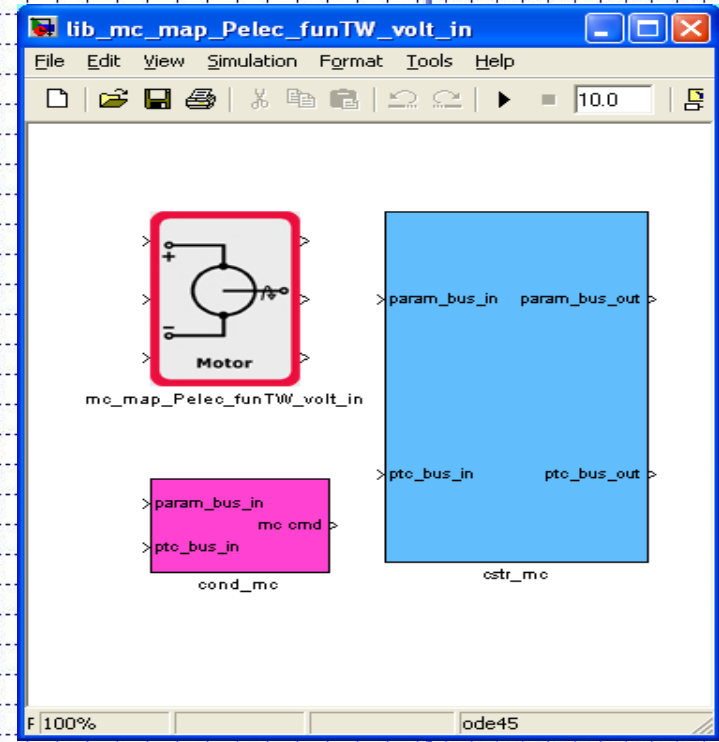
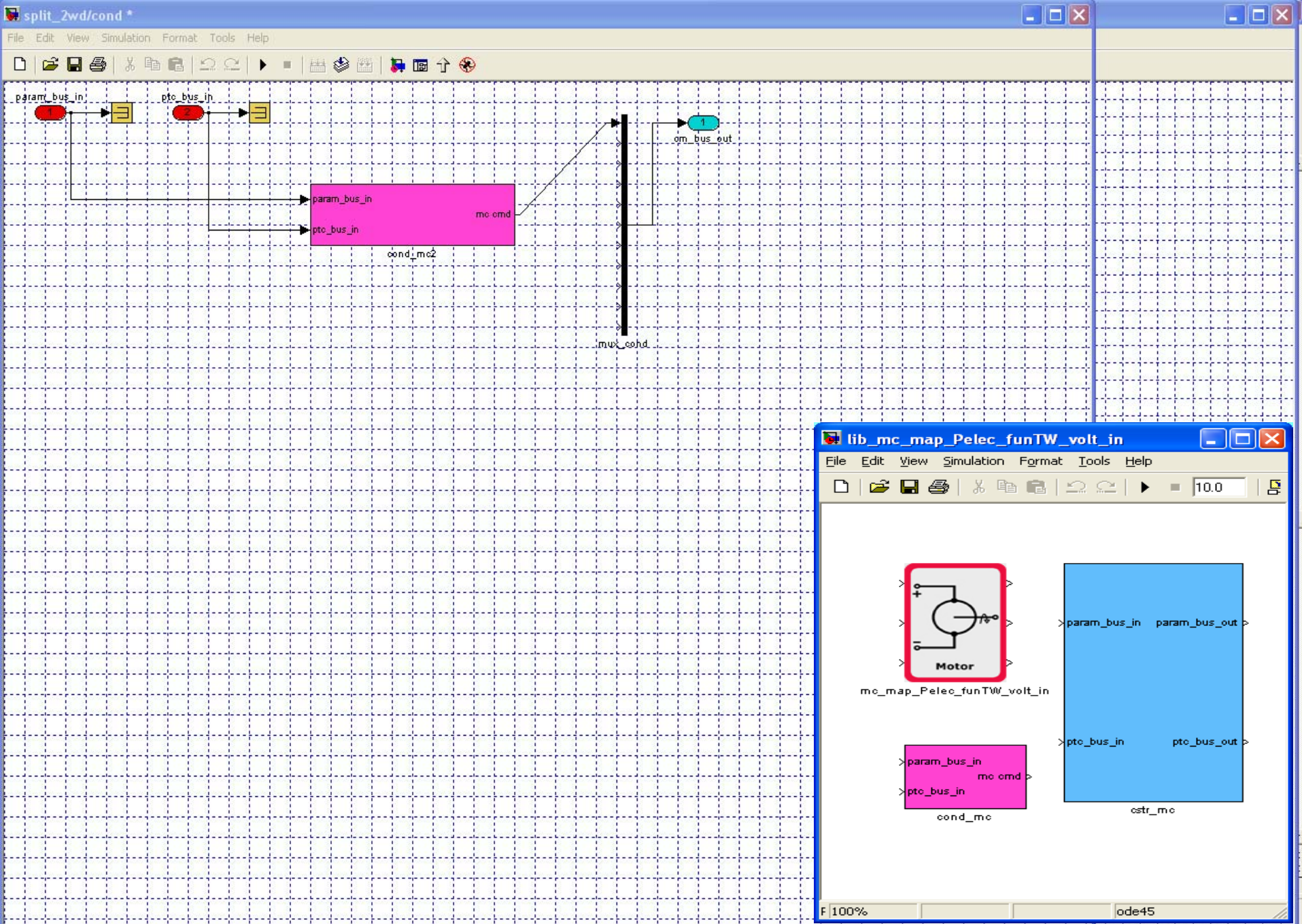


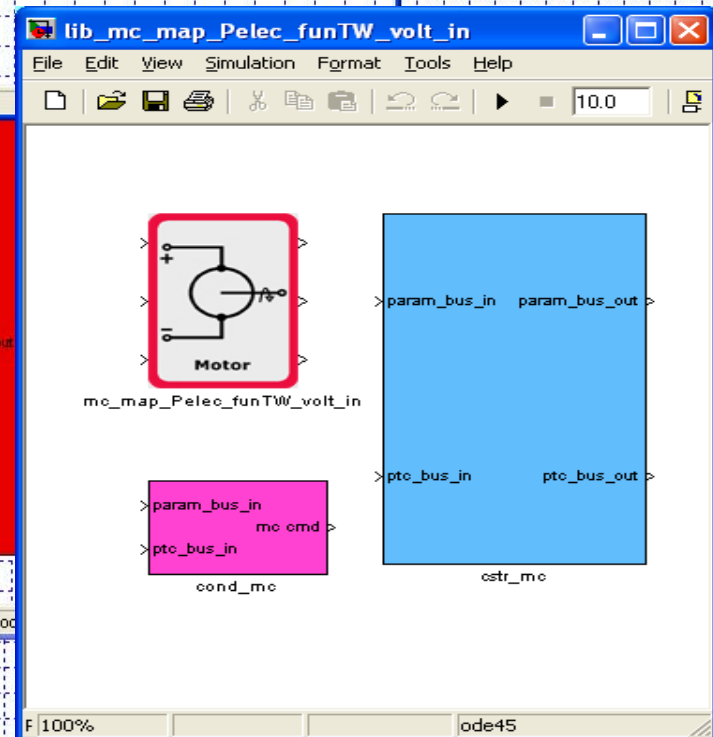
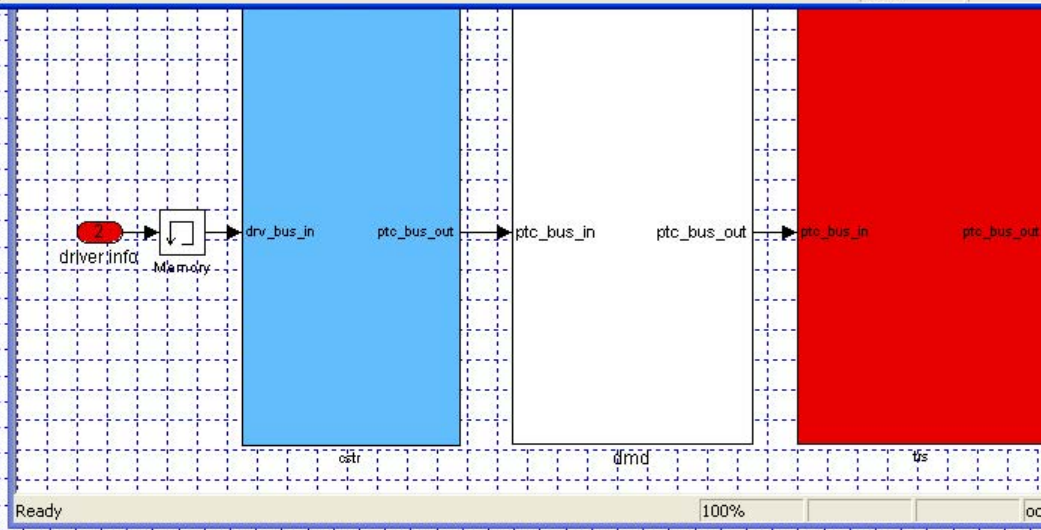
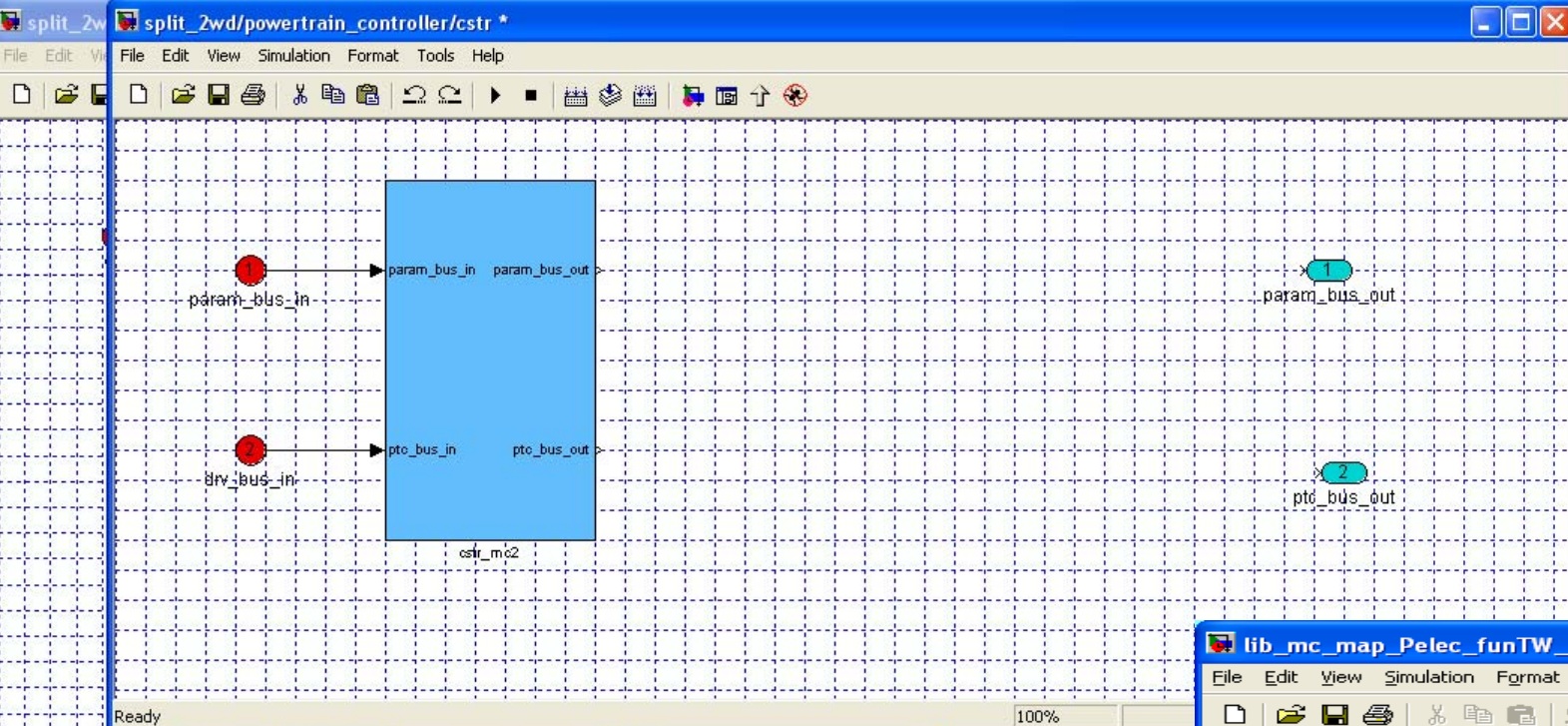


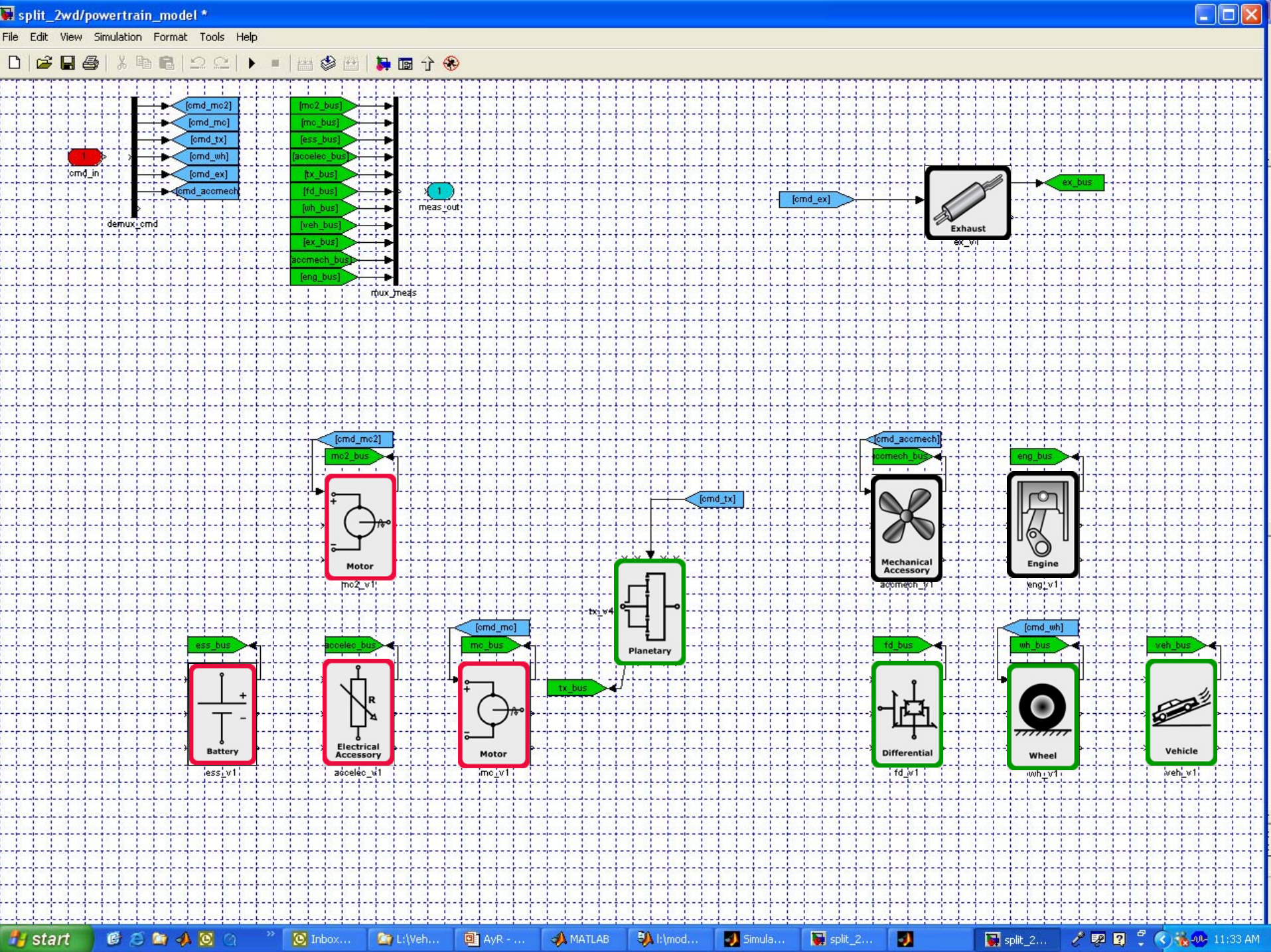


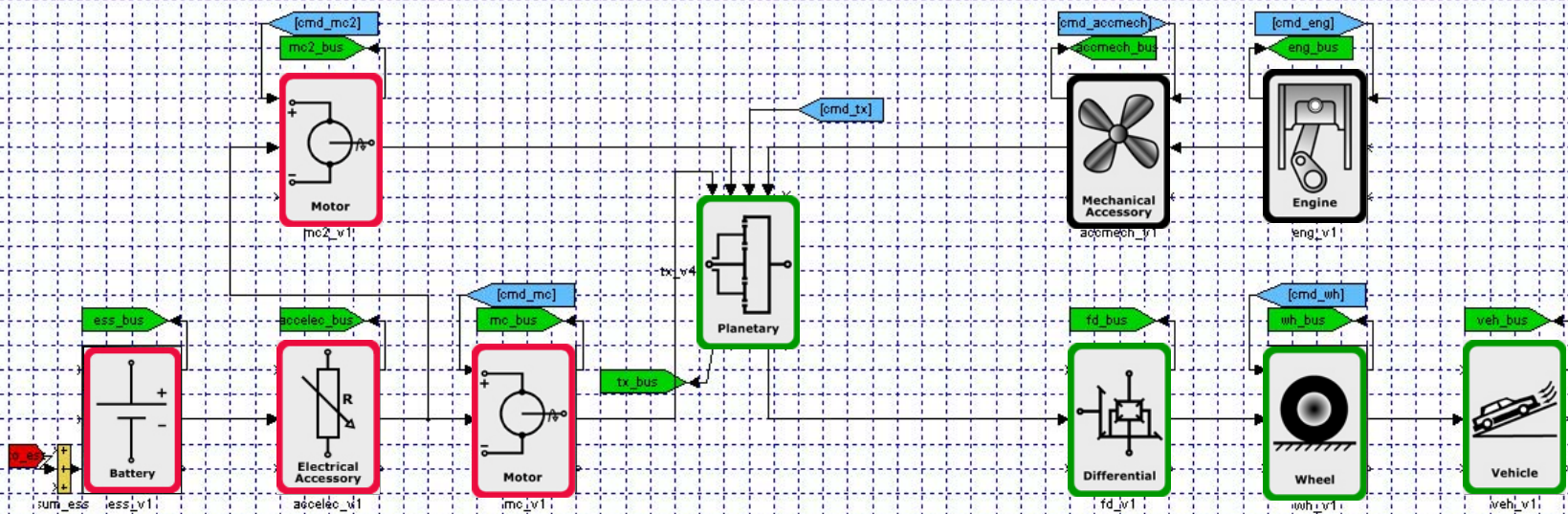
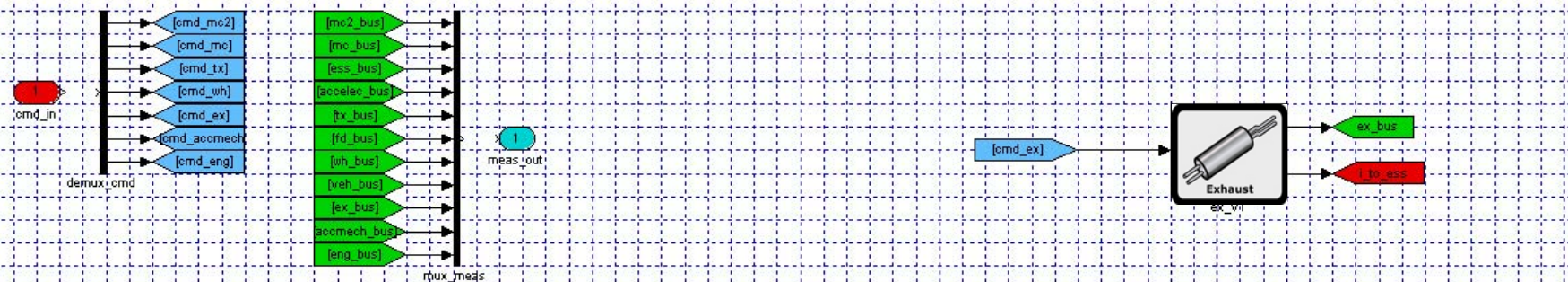


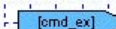


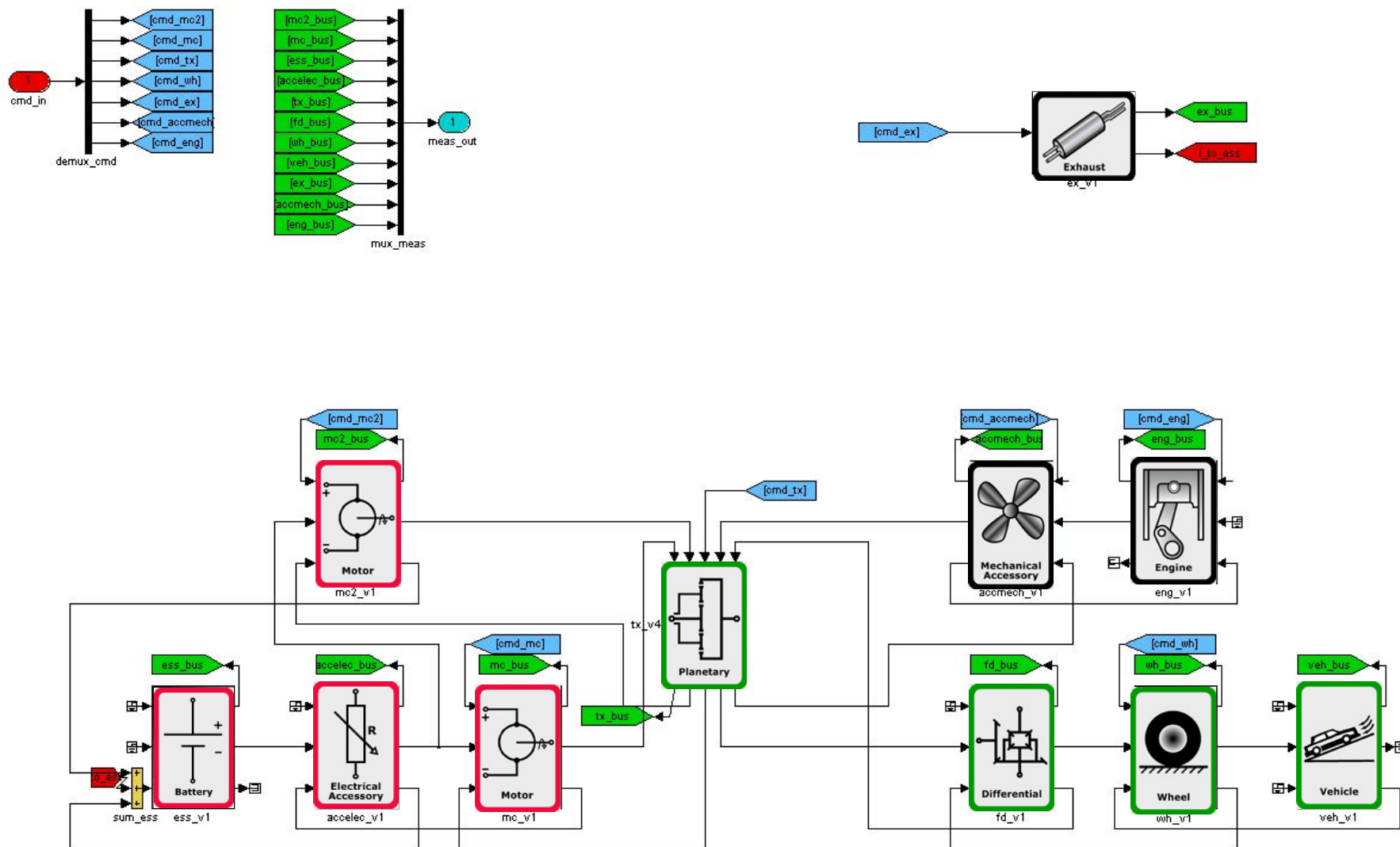


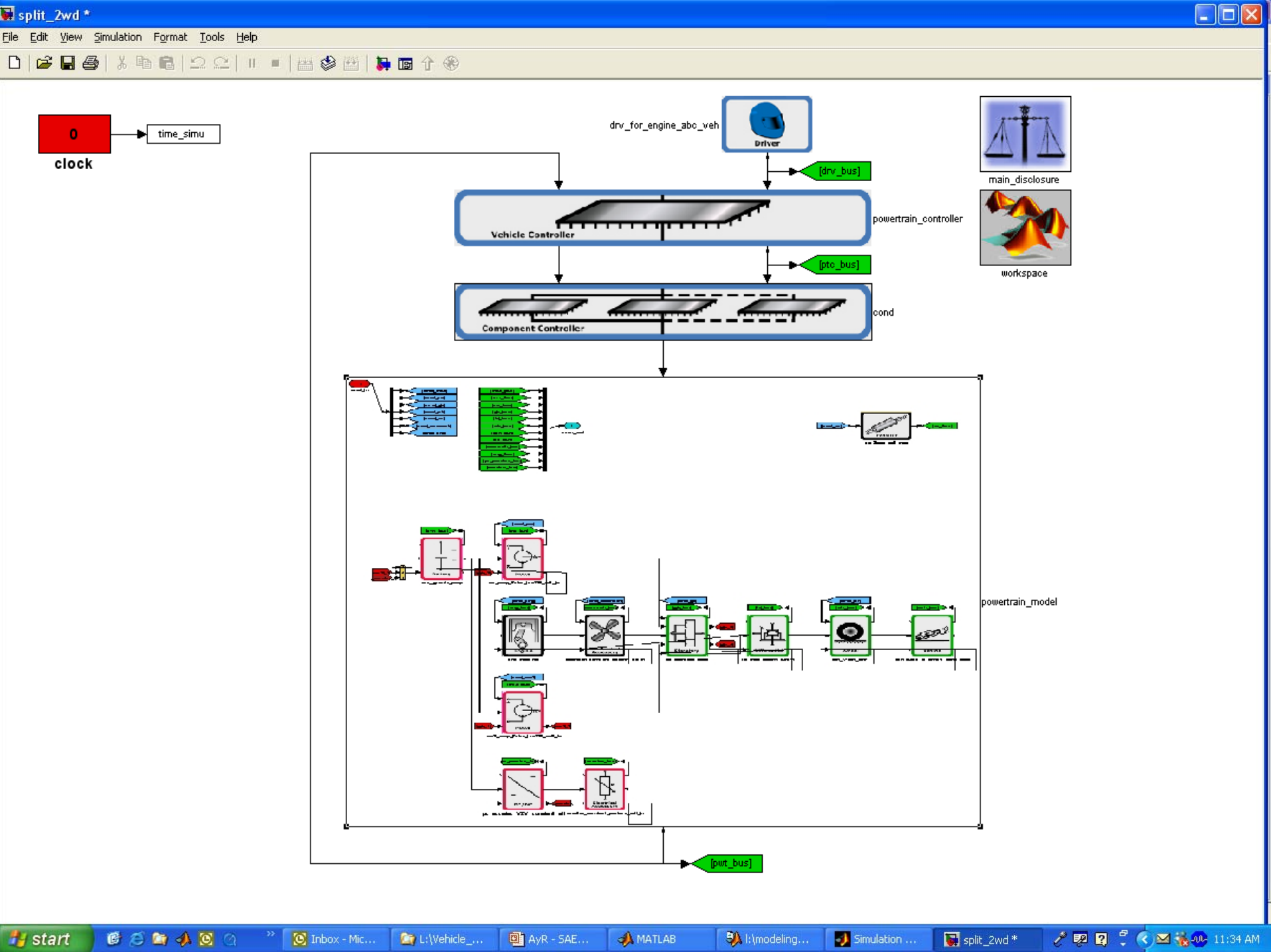






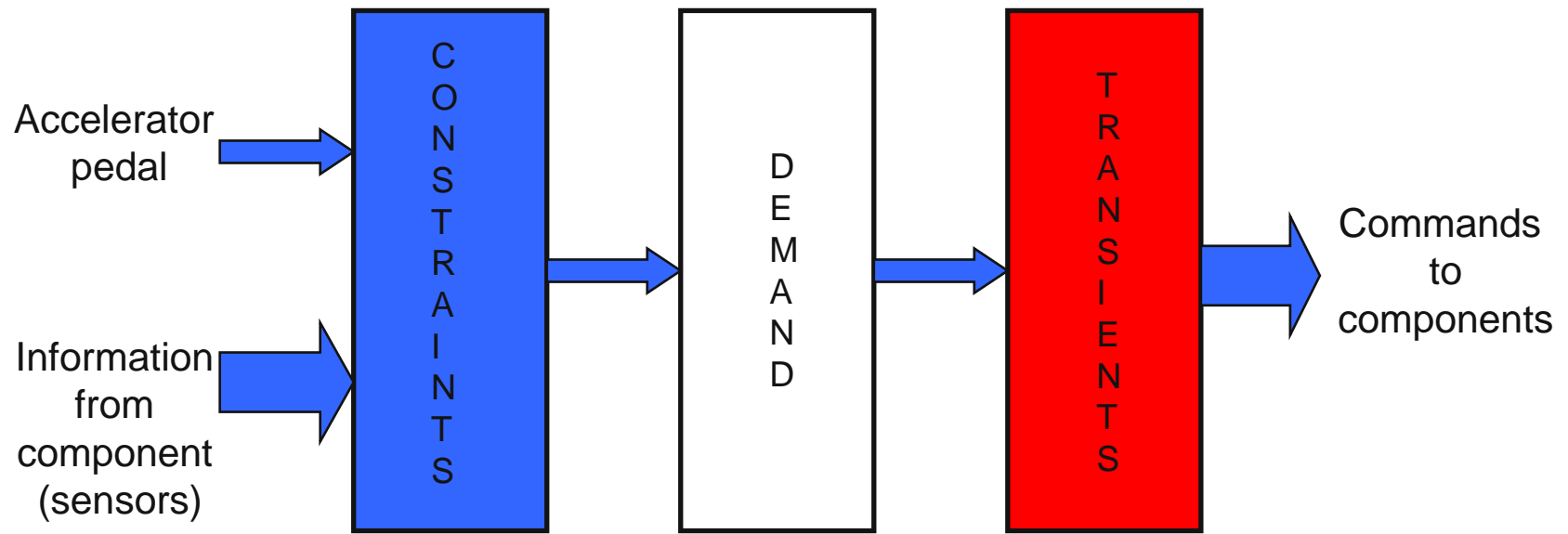




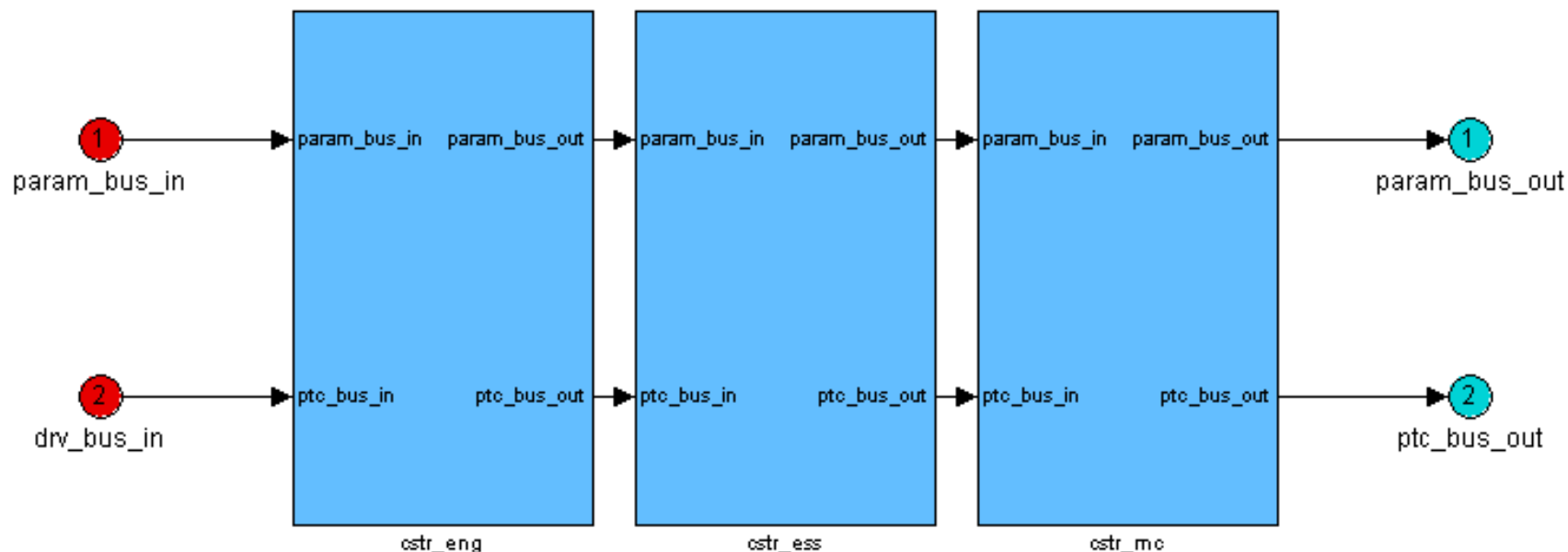


Generic Power Controller Organization

A generic organization common to all powertrains

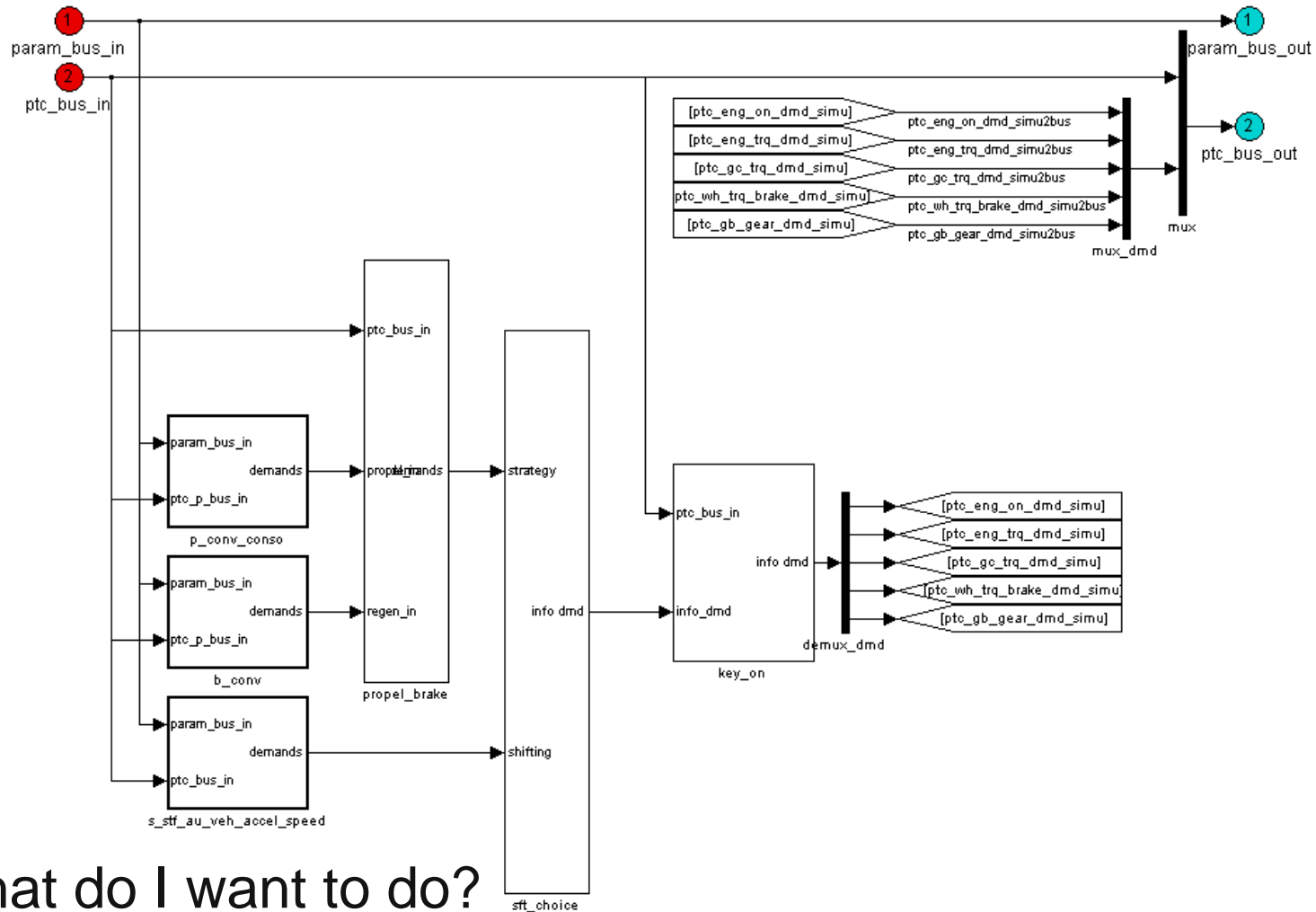


Constraint Block In Simulink



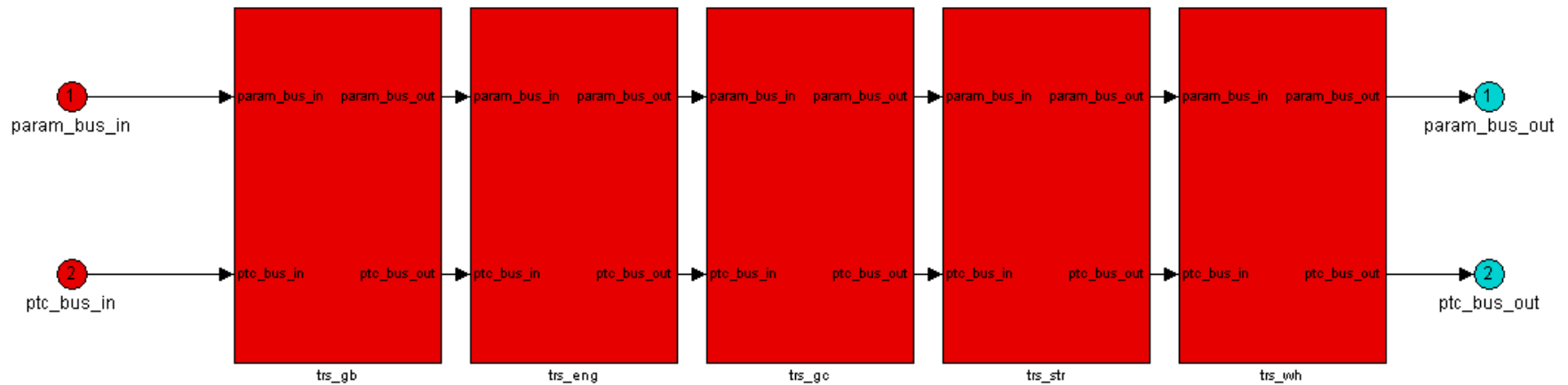
What can I do?

Demand Block In Simulink



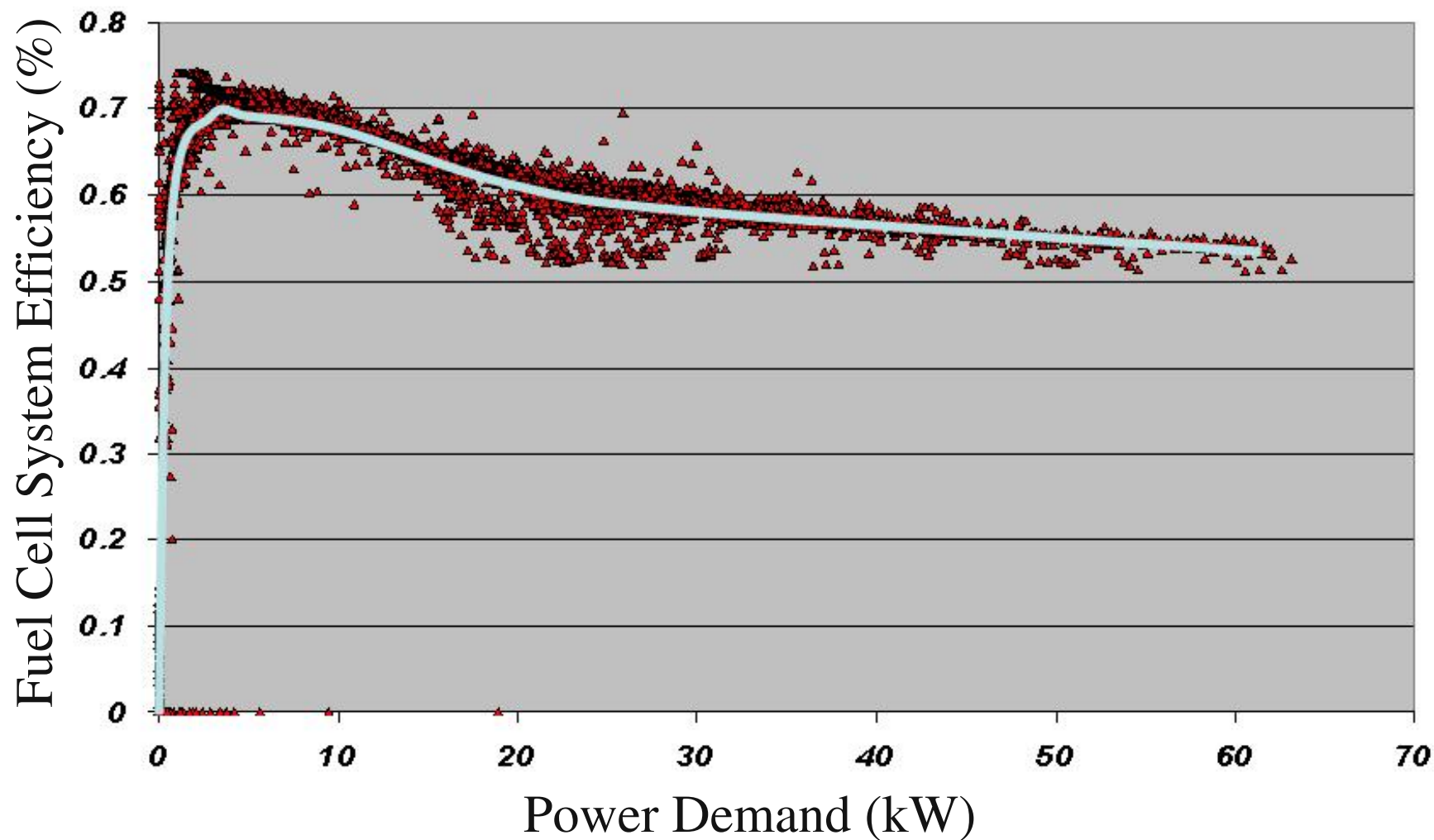
What do I want to do?

Transient Block In Simulink



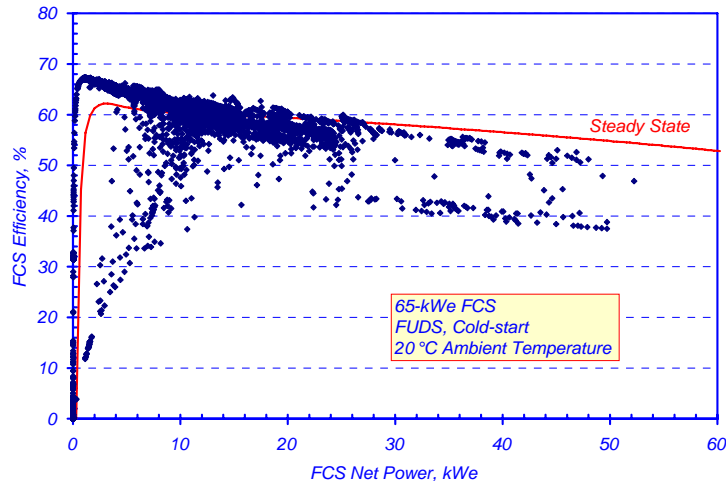
How do I do it?

Different Models for Different Simulations

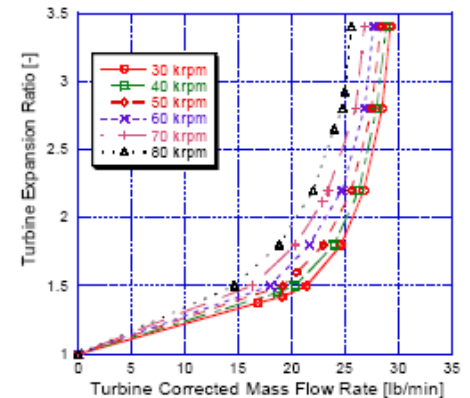


Examples of High-fidelity Models Integration

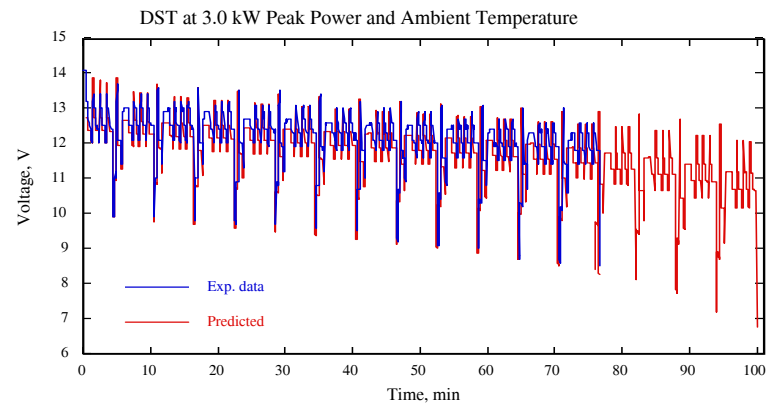
Transient, thermodynamic, physically-based,
crank-angle resolved, turbocharged,
intercooled diesel engine.



Transient, thermodynamic, physically-based,
fuel cell models with Argonne,
based on GCtool

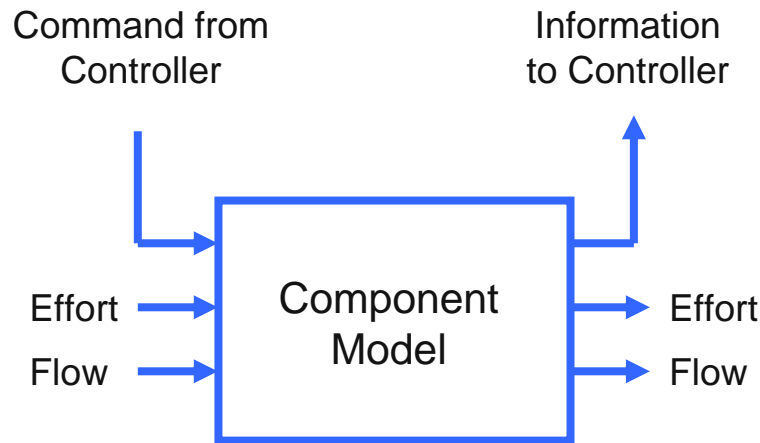


The battery model developed at the Penn State GATE
Center is a thermal-electrochemical coupled model
constructed on computational fluid dynamics.



Model Complexity Selection Facilitated by Generic Component Model Format

- Models follow Bond Graph principle
- Consistent input/output nomenclature
- Plug-and-play component models
- Configuration easy to visualize in block diagram code



Mechanical Component

Effort = Torque

Flow = Speed

Electrical Component

Effort = Voltage

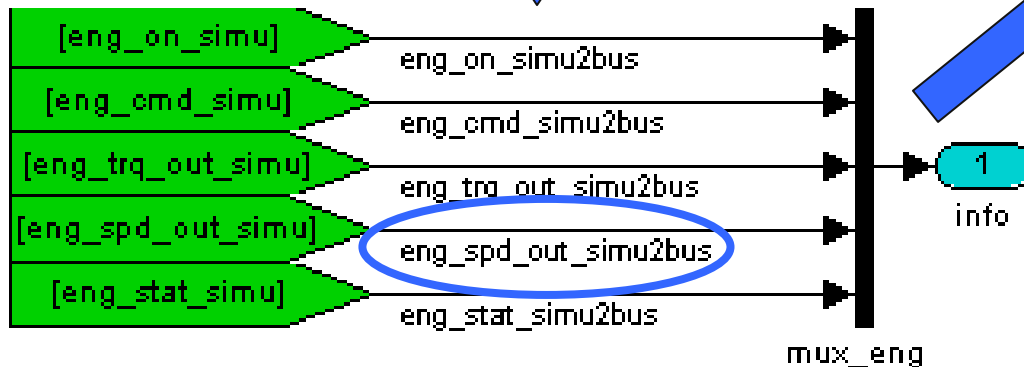
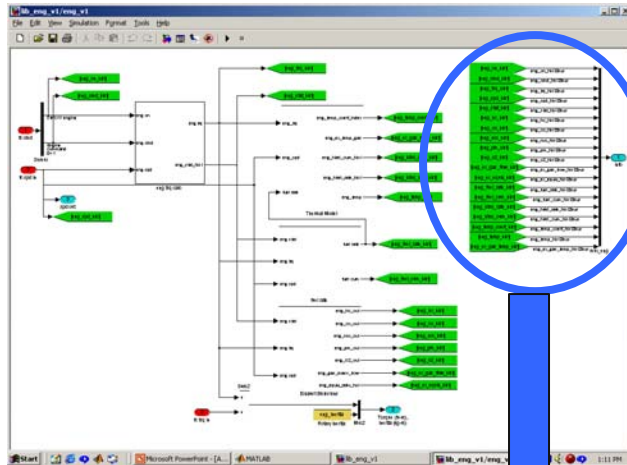
Flow = Current

Nomenclature Allows Intuitive Parameter Understanding

- Based on three parts:
 - Type of component (e.g.: eng = engine)
 - Type of data (e.g.: trq = torque)
 - Complement of information (e.g.: max = maximum)
- All the model parameters and variables are composed using these three parts

Parameter	Type of component	Type of data #1	Type of data #2
eng_spd_out_simu	"eng" for engine	"spd" for speed	"out" for output
mc_volt_in_simu	"mc" for motor controller	"volt" for voltage	"in" for input
ptc_eng_trq_max_simu	Engine information used in the controller ("ptc")	"trq" for torque	"max" for maximum

Information Bus Automatically Created



Block Parameters: eng_spd_simu

Selector

Select or reorder specified elements of an input vector or matrix.
 If "Use index as starting value" option is not checked
 $y = u(\text{elements})$ for vector input
 $y = u(\text{rows}, \text{columns})$ for matrix input
 Otherwise
 $y = u(\text{element}:\text{element}+\text{outdim}-1)$ for vector input
 $y = u(\text{row}:\text{row}+\text{outdim}(1)-1, \text{column}:\text{column}+\text{outdim}(2)-1)$ for matrix input
 where outdim is the value specified in the "Output port dimensions" parameter.
 The source of element (E) or row (R) and column (C) indices may be the block's dialog (internal) or an input port (external).

Parameters

Input type: Vector

Index mode: One-based

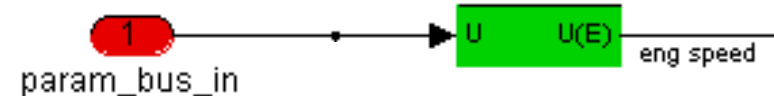
Source of element indices (E): Internal

Elements (-1 for all elements):
 nb.eng_spd_out_simu

Input port width:
 nb.pwt_variables

☐ Use index as starting value

OK Cancel Help Apply

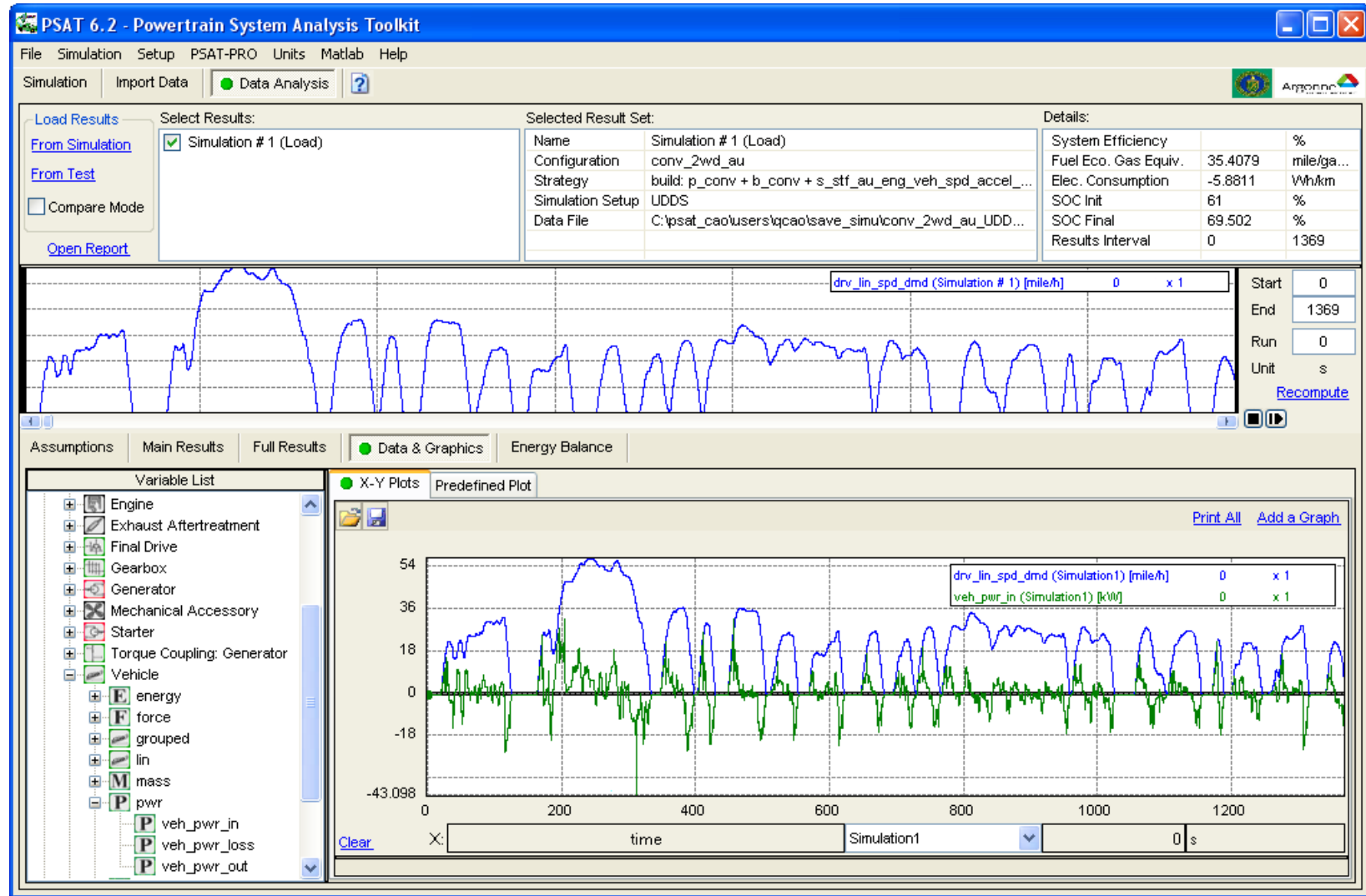


Name of the line =>
 “name_parameter”2bus

Run Batch Mode & Ensure Simulation Traceability

- Several simulations can be successively run to:
 - Perform parametric studies
 - Evaluate different drive cycles
 - Compare different powertrain configurations
 - Evaluate component technologies and sizing...
- Traceability is insured by saving several files, including:
 - MAT-file with initial parameters and simulation results
 - M-file used to rerun the exact simulation
 - .xls file used to compile all results from same study

User Interface Allows Faster Post-processing Analysis



Test Data Post-processing Automated

PSAT 6.2 - Powertrain System Analysis Toolkit

File Simulation Setup PSAT-PRO Units Matlab Help

Simulation ☒ Import Data Data Analysis ?

Project File: Configuration ☒ Setup Run

☒ Conversion Export

Data File: projects\Prius_MY04\60509007_UDDS_Sample_data\60509007_UDDSDdata.txt File Date: 3/22/2007

Variable List	Variable Name	Unit	Length
DilAir	Pedal_Force_Brake_1Ch16	lbs	
PVR	Pedal_BrakeStroke_3Ch9	%	
Eng	Pedal_AccelPos_3Ch11	%	
MOTOR1			
Pedal			
Brake			

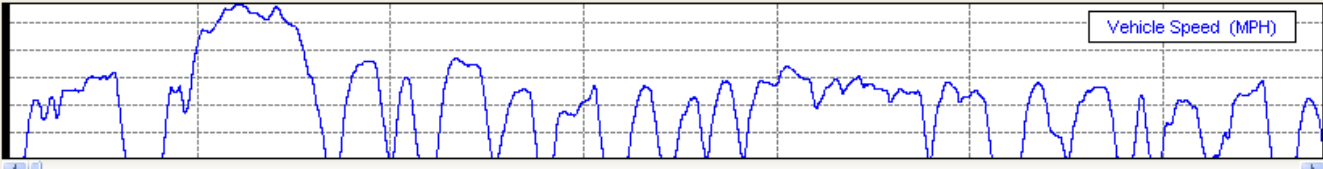
[Load All Data](#) [Load Variable List](#)

Variable Name	Unit	Unit Conversion	PSAT Component	PSAT Variable Name	PSAT Unit
THC	mg/s	No Unit Conversion			
THC_dil	ppm	No Unit Conversion			
Time	s	No Unit Conversion			
Tire_Temp	F	No Unit Conversion			
Vehicle Speed	MPH	No Unit Conversion			
VH	V	No Unit Conversion			
VL	V	No Unit Conversion			
VSV_CanisterClosed_3Ch15	volts	No Unit Conversion			
Wheel_Spd_1Ch12	rpm	No Unit Conversion			

[Remove all](#) [Remove Selected Variables](#) [Remove Conversion for Selected Variables](#)

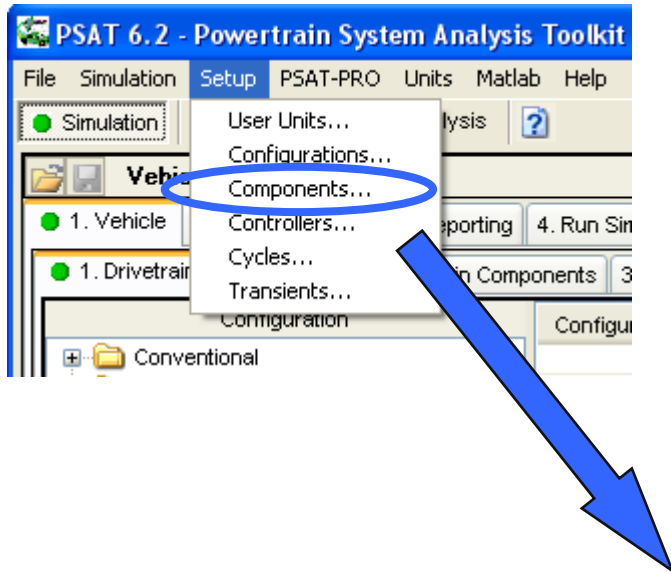
Template File: [Apply Template](#) [Load Variables in Matlab](#)

Preview

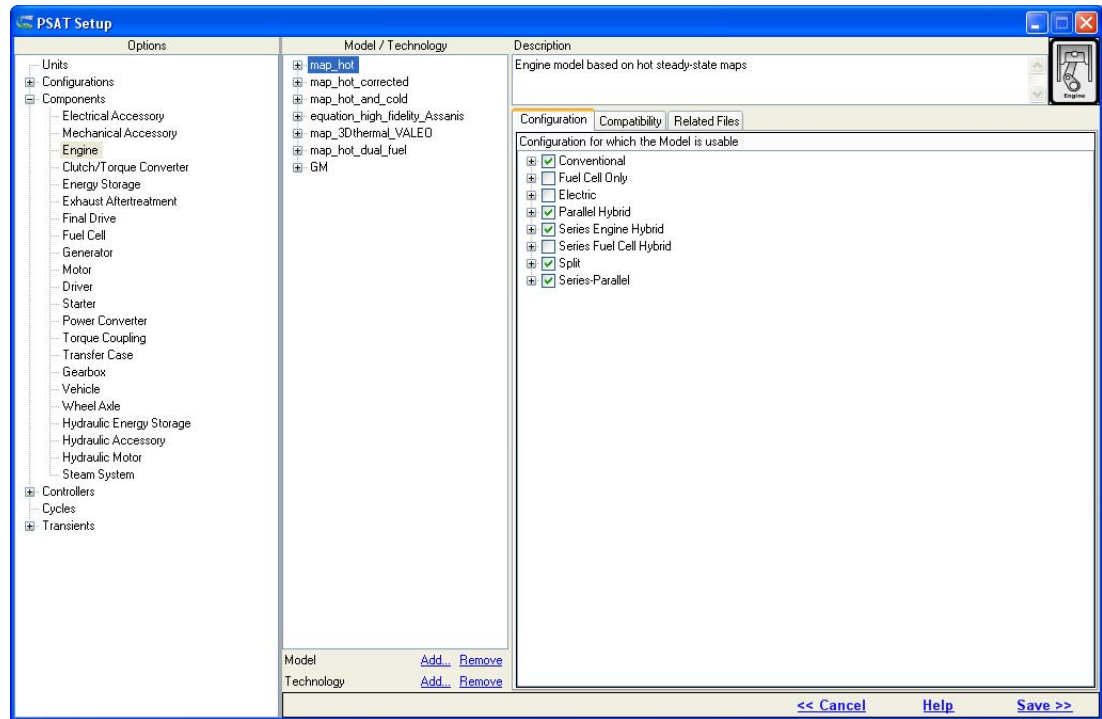


	Index	Var
Start	0	0.00244
End	13725	0.00308
Run	0	0.00244

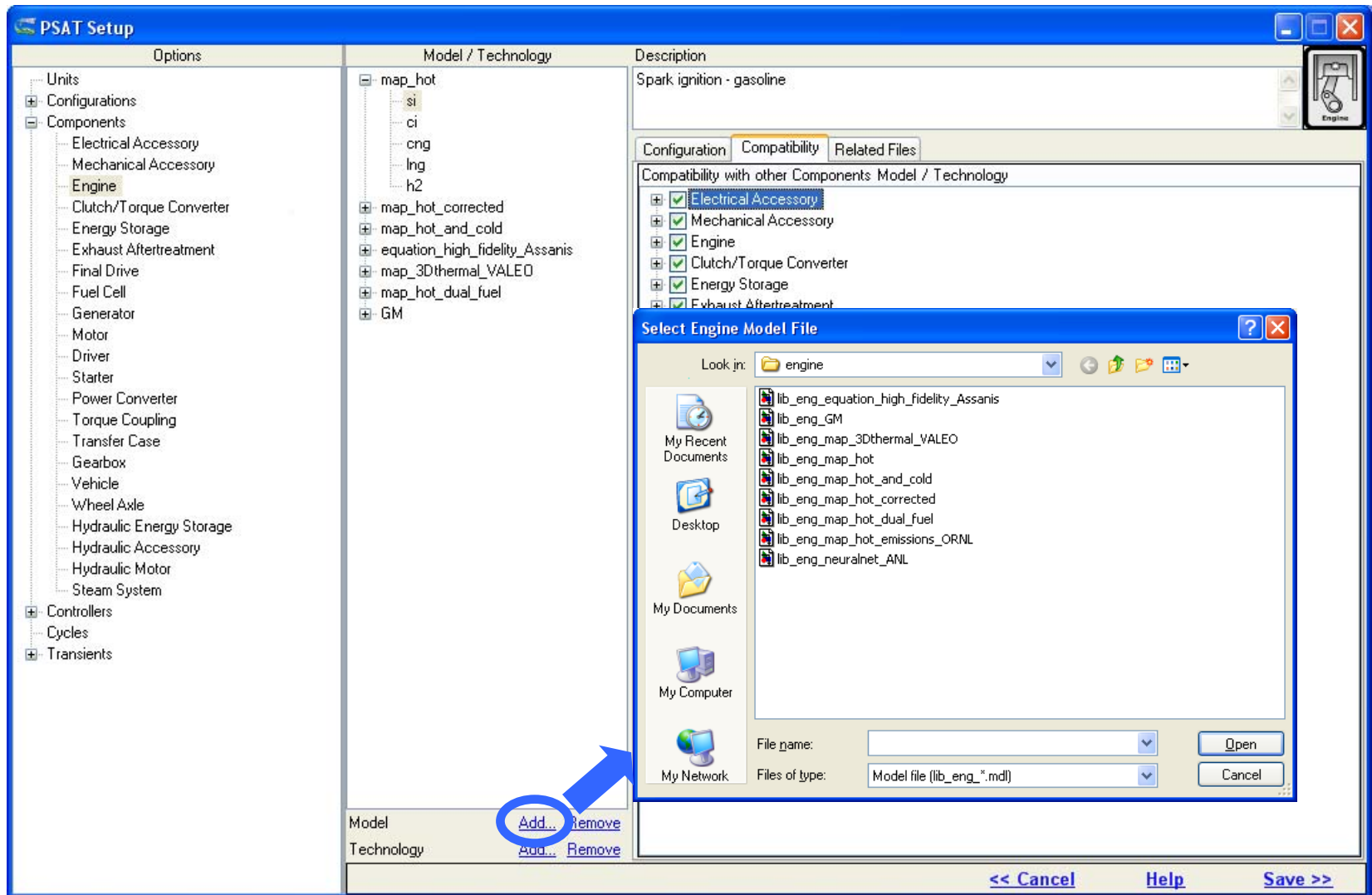
Proprietary Information Are Added Without Code Modification



Menu used to change the units, the configurations, components and controllers compatibilities



Add/Remove Model



Flexible and Reusable Tools Ensure Resource Leverage

■ Maximize Flexibility

- Powertrain build automatically
- Proprietary data set, component models and control strategies implemented without code modification
- Level of modeling can be selected
- Intuitive Graphical User Interface

■ Maximize Reusability

- Generic component model format
- Avoid component model duplication by creating copied version using API
- No Masks are used to avoid several evaluations of the same files
- Control strategy organization allows reuse of parts of the control for several powertrain configurations
- Naming nomenclature allows use of generic post-processing
- Functions are used whenever possible

PSAT Is Flexible & Reusable

- Drivetrains constructed from user choices
- Numerous configurations can be explored(>150: conventional, parallel, series, power split...)
- Several strategies can be compared within the same model using switches
- Can add new component data, models and control
- Model format is generic (3 inputs / 3 outputs)
- Multiple uses of same model possible
- Software is highly parameterized

PSAT Is User-Friendly

- Easy integration of initialization files, component models or control strategies through its Graphical User Interface
- Easy comparison of different levels of model sophistication and control strategies
- Post simulation analysis is enhanced through use of a voltage bus for more realistic transient behavior

PSAT has been designed to take transients into account and handle different levels of modeling detail ... allowing the user to match the level of sophistication with the application.

Outline

- ANL Philosophy
- PSAT Overview
- Example of Studies
- Perspectives

GPRA & MultiPath Studies

■ Objective:

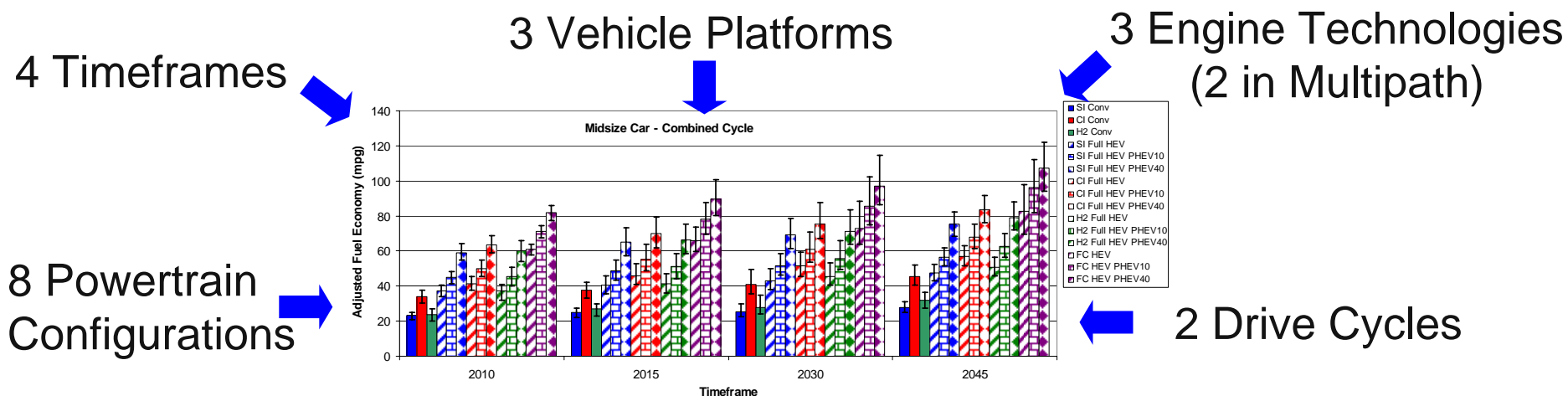
Evaluate fuel displacement impact of DOE activities

■ Results:

- Simulated > 700 vehicles in GPRA, > 400 in Multipath
- Introduced risk analysis to evaluate uncertainty (low, medium, high)

■ Future GPRA/Multipath Studies

- Continue to refine assumptions
- Perform Monte-Carlo analysis (similar to GREET)



Fuel Consumption Sensitivity

■ Project Description / Objectives

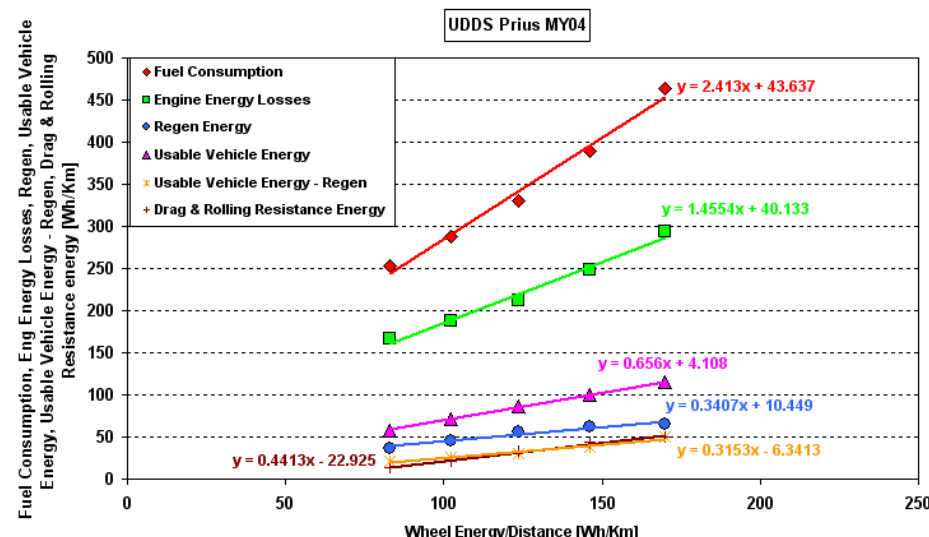
- Understand the fuel consumption sensitivity of conventional and HEV for different driving cycles (e.g. differences between EPA and real world driving)
- Revisit the initial study based on vehicle test data (but limited sensors) to gain further insight.

■ Accomplishments

- Validation of fuel consumption trends between test and simulation
- Deeper analysis of Focus and Prius
- Engine efficiency is the main factor followed by usable and regenerative energy

■ Status

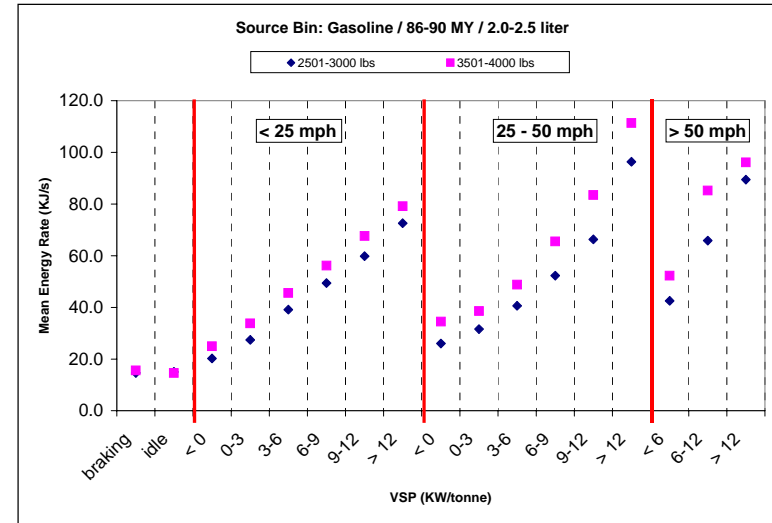
- Work Completed in July 2006



Collaboration with EPA Provides MOVES Inputs



- EPA licensed PSAT and was trained
- Study focused on using PSAT instead of PERE (backward model) for increased accuracy
- PSAT was modified to be able to directly provide inputs to MOVES
- Several vehicle platforms and configurations were modeled for different timeframes
- Results were presented at SAE Government/Industry meeting
- In FY06, the error from the Binning methodology will be evaluated



A Next Generation Modeling Framework for Well-To-Wheel Analysis of Hydrogen Fuel Cell Vehicle Scenarios

SAE Government / Industry Meeting
May 10, 2005

John Koupal
U.S. EPA Office of
Transportation & Air Quality

Michael Wang
Argonne National Laboratory
Transportation Technology R&D Center



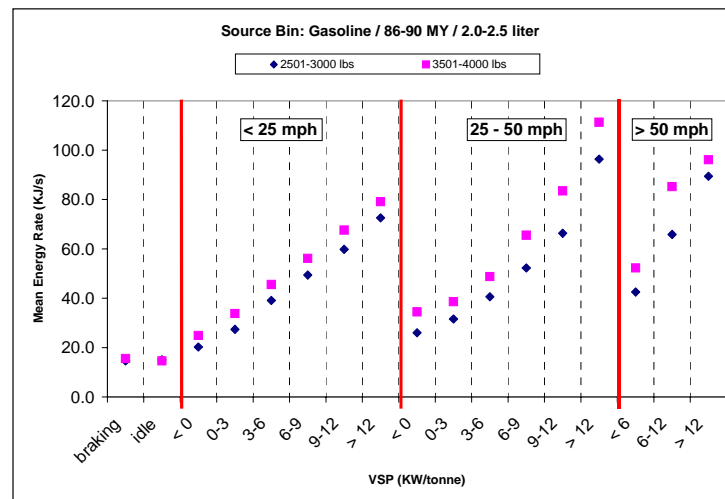
Evaluation of MOVES Fuel Economy Uncertainties

■ Project Description / Objectives

- Evaluate the error introduced by the binary approach used in MOVES
- Collaboration with EPA

■ Accomplishments

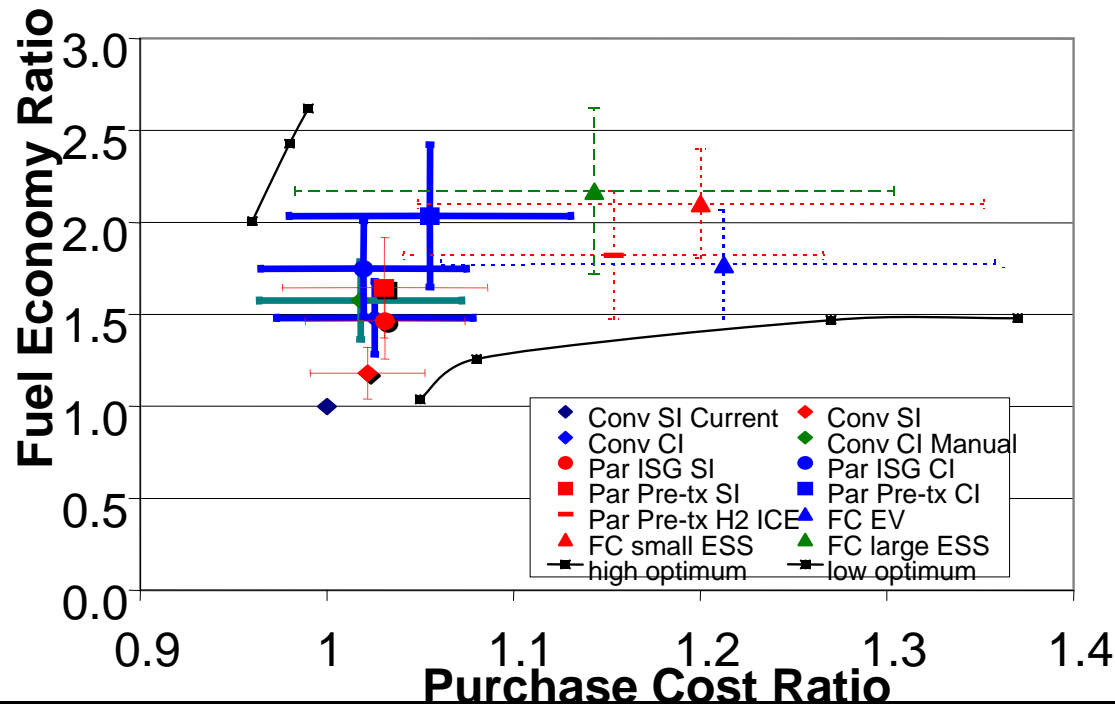
- Implement the methodology in PSAT
- Validate the approach with conventional vehicles
- Assess impact on HEVs (both, ICE and fuel cell)



	Japan1015	UDDS	HWFET	LA92	NEDC	US06
EPA MOVES	76.5	75.3	69.9	54.2	55.5	51.4
PSAT	74.8	73.0	65.6	58.5	59.8	45.3
Difference	1.7	2.3	4.3	-4.3	-4.3	6.1

Integration of ORNL Automotive System Cost Model (ASCM) in PSAT

- Integrated tools will allow DOE to perform trade-off studies between fuel economy and cost for advanced vehicles.
- Based on FreedomCAR goals, fuel cell vehicles will be competitive from a cost point of view.
- For slow technology development, diesel hybrids offer an interesting solution.



Collaboration with CATARC Mitigates Global Petroleum Concerns

CATARC

- China Automotive Technology and Research Center (CATARC) signed a Memorandum of understanding in March 2004 with Argonne
- Two engineers from CATARC were trained at ANL for 3 months on PSAT.
- A common paper will be published assessing the impact of several advanced vehicle configurations for China from a total cycle prospective.
- Following the study, PSAT was licensed to CATARC in April 2005.
- A PSAT training for Chinese Automakers and researchers working with CATARC is scheduled for FY06



PSAT Simulations Support DOE R&D Activities

■ Vehicle Mass Elasticity Analysis - Support for Ro Sullivan

Goal: Are advanced vehicles more sensitive to mass than conventional?

Results:

- (1) The mass reduction benefits hybrids more than non-hybrid vehicles when they are not resized for performances
- (2) The mass reduction benefits non-hybrid more than hybrid vehicles when they are resized for performances

■ Rule of thumb for Fuel Economy sensitivity to mass, drag coefficient and rolling resistance – Support for Phil Paterson & Ken Howden

Goal: How much does the fuel economy change as a function of a parameter?

Results:

10% Mass changes fuel economy by 4 to 6%.

10% Cd changes fuel economy by 1.5 to 2%

10% Rolling changes fuel economy by 1.5 to 2%

Values for other percentage changes were also provided.

PSAT Simulations Support DOE R&D Activities

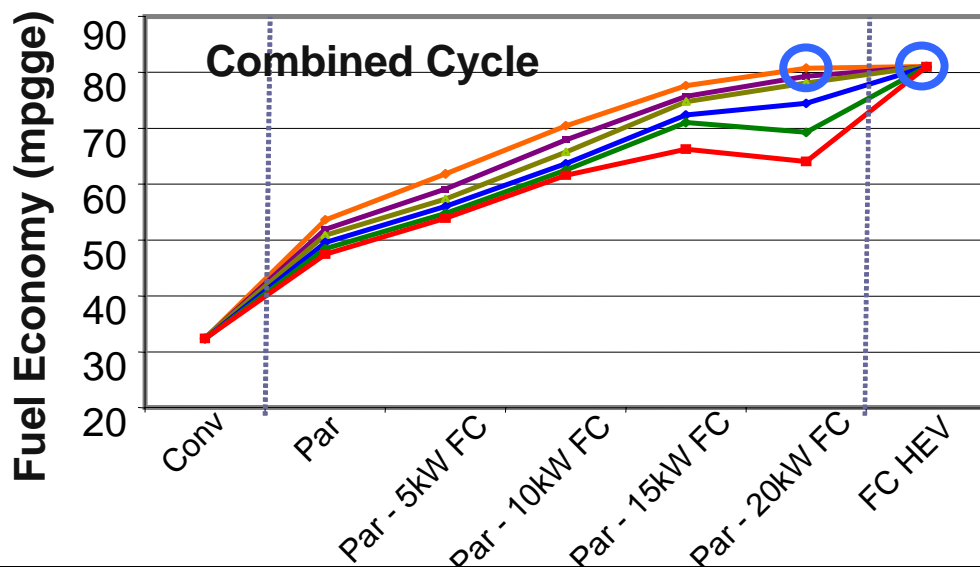


■ Combining H₂ ICE and Fuel Cell for Propulsion - Support for Sig Gronich

Goal: Can we increase FE and range by combining H₂ ICE and Fuel Cell?

Results:

- (1) The addition of fuel cell (even with low power) allows both fuel economy and range increases.
- (2) Adding a 10kW fuel cell to parallel HEV system increases the range by more than 20% and 30% for a 20kW fuel cell.
- (3) 20kW fuel cell achieves similar fuel economy as fuel cell HEV.



PSAT Simulations Support DOE R&D Activities

■ **Advanced Vehicles Fuel Economy for GREET 1.7 and GPRA – Support for Michael Wang & Phil Paterson**

Goal: What is the fuel economy of advanced vehicles (ICE HEVs and fuel cell) for several vehicle platforms and timeframes?

Results:

- (1) Fuel economy values implemented in GREET 1.7.
- (2) First round for GPRA performed in July.



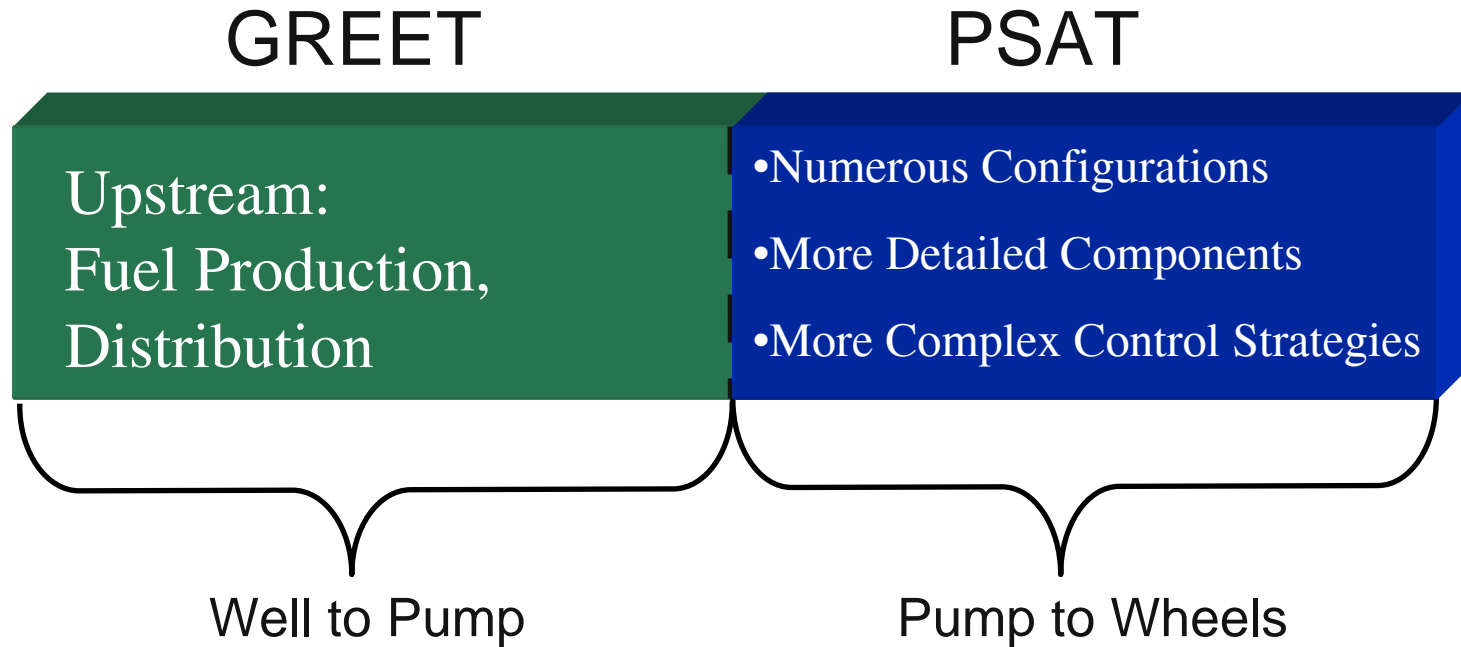
■ **Future Technology Evaluation – Support for Fred Joseck**

Goal: What is the fuel economy ratio of advanced vehicles (ICE HEVs and fuel cell) for several vehicle platforms and timeframes?

Results:

- (1) More than 100 vehicles were defined with slow and fast technology cases
- (2) Fuel economy ratios were provided for compact, midsize and SUV for several timeframes (2010, 2020, 2035, 2050)

Implication of Achieving FreedomCAR Goals for Fuel Economy and Well-to-Wheels Green House Gas Emissions



- Hydrogen ICE hybrids offer a near-term solution to accelerate the development of a hydrogen infrastructure
- To compete with diesel hybrids, a cost-effective renewable energy pathway for hydrogen production needs to be considered for long-term applications.

Students Used PSAT in Challenge X as a Design Tool



- cX teams have completed a powertrain selection process
- PSAT was used for:
 - Comparison of dozens of powertrain configurations and components to meet the competition goals.
 - Component sizing.
 - Development of specific control strategies for the powertrain architectures.
 - Control components in real time.

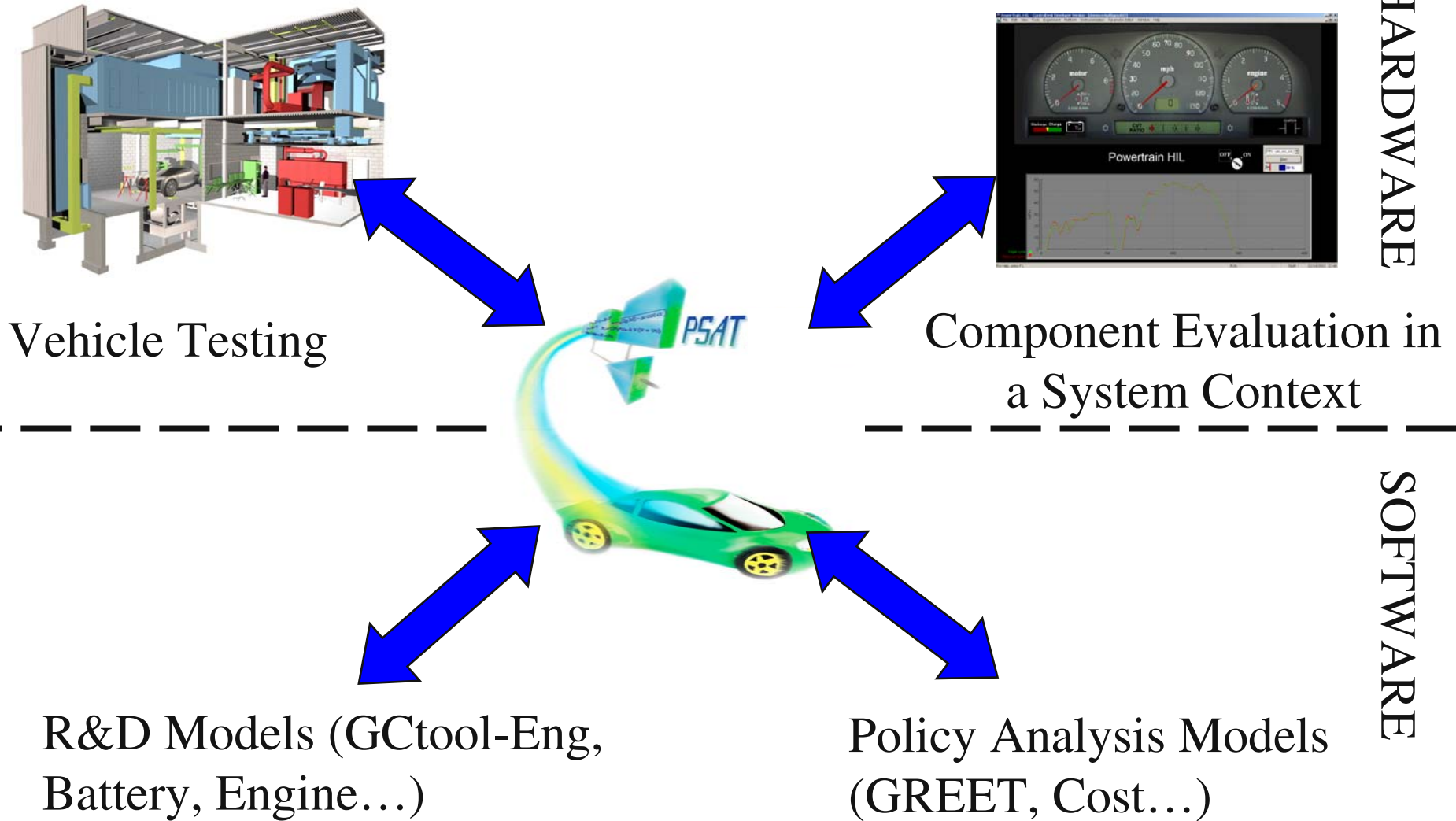


➡ Successful selection and development of powertrain within the time frame considered made possible through flexibility and reusability process

Outline

- ANL Philosophy
- PSAT Overview
- Validation
- Example of Studies
- Perspectives

PSAT Ensures Synergy Of Programs



Summary / Perspectives

- PSAT is a state-of-the-art powertrain modeling tools allowing users to simulate unrivaled number of pre-defined configuration
- PSAT has been developed for external users and development emphasized on easy integration of initialization files, component models and control strategy integration
- PSAT simulates transients and allows realistic control